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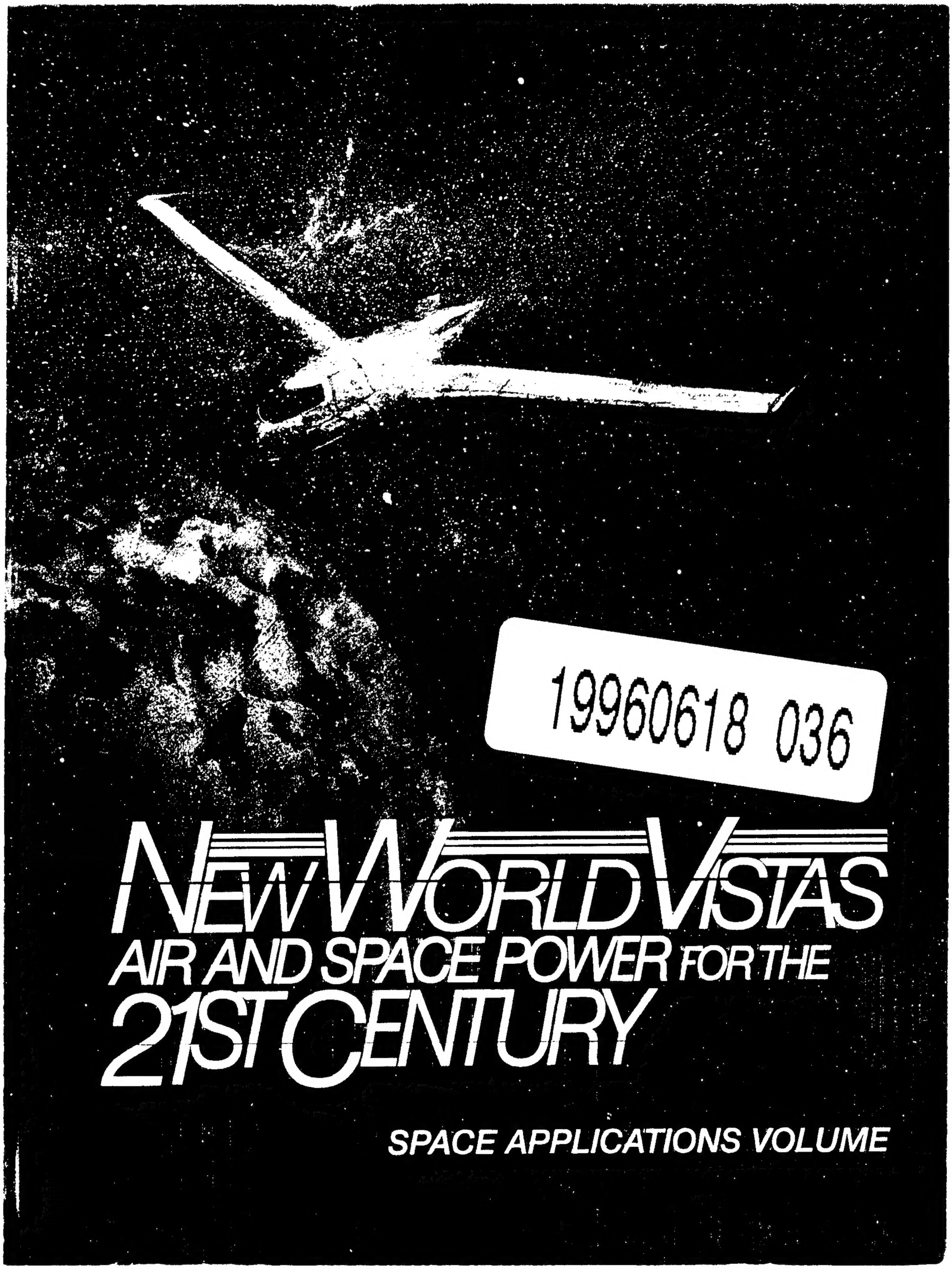

NEW WORLD VISTAS
AIR AND SPACE POWER FOR THE 21ST CENTURY

SPACE APPLICATIONS VOLUME

NEW WORLD VISTAS

AIR AND SPACE POWER FOR THE 21ST CENTURY

SPACE APPLICATIONS VOLUME

This report is a forecast of a potential future for the Air Force. This forecast does not necessarily imply future officially sanctioned programs, planning or policy.

Executive Summary

Military Foundations of Space Application

Space is the ultimate high ground. It is substantially different from air, land and sea because operations in space are truly global by nature. Space is fundamental to achieving global presence, global reach, and global force. The challenge in this new age is how to efficiently manage our space assets consistent with rapid commercial technology evolution and limited defense budgets.

Modern day thought about the utilization of space stands where our thinking about the airplane stood at the early stages of World War I - as scouts or messengers. We must go back to first principles, to tie this new warfighting medium with its remarkably new, often counter intuitive operating environment into a set of fundamental warfighting principles. The need for information dominance of the battlefield and the critical nature of winning at information warfare leave us no choice.

As world population and economic pressures grow, political and market boundaries blur, the information explosion accelerates, capability growth and technological advances in commercial space abound, and supra-national entities take on a growing role on the geopolitical scene, the United States freedom of action to operate in space will be severely constrained. Future military space planning must recognize that access to space will be widespread and adversaries will also use it for their purposes. Extremely capable space systems and their products, until recently protected by strict security and trade restrictions, will be available to all buyers on the commercial market. The producers, owners and operators of these systems will include domestic and foreign governments and corporations as well as alliances and multi-national consortia.

We are witnessing a revolution in military affairs. It is the recognition that information dominance of the battle space and winning at information warfare are key to the success of joint and coalition warfare. In fact, information warfare may be more effective in collapsing an enemy than traditional military force. Space systems enable maintaining a high tempo of combat operations day/night and in all-weather. The product of information dominance is an integrated and synchronized force with decisive combat power which can be applied at the desired time and place, rapidly overwhelming the enemy with minimal friendly losses or collateral damage. Critical to making this happen is space systems support to the warfighter, which produces a significant force multiplier effect.

The need for the integration of all space assets to provide the force multiplier requires a paradigm shift from the old way of thinking about space. For years the military has considered space in the context of tasks like communications and navigation, or mission areas such as space control and force enhancement. This view of space utilization is channeled by these over-simplified but convenient definitions. We need a "system of systems" approach, rather than the stove pipe single mission approach of the past. This overarching system must include future dedicated military space capabilities and civil, commercial, national and international assets in a complementary way.

The time tested principles of war give us new insights about the use of space systems in future warfare. These principles are still applicable, and their implementation is enhanced by

the new dimension of space and its impact on terrestrial warfighting forces. In fact, a review of the functional areas and the principles leads us to several key drivers that need to be stressed in any future space architecture:

Changing of current technology push to user pull focus

Conversion from independent missions to missions integrated with terrestrial forces

Evolution of military doctrine based on appreciation of the contributions of space

Understanding the utility of space by the land, sea and air combat elements

Operation of space systems that can be maintained with minimum manpower

Dramatic reduction in cost through more effective cost control.

Future Vision of Space Application

The contribution of space systems to information-based warfare has become central to military operations. Space based sources and transmissions are crucial for the "information" in information-based warfare, so that U. S. forces can respond to changing operating environments and evolving threats. A huge mass of data is available from sensor systems, and many different sources, and this data needs to be processed into information useful to the warfighter. He needs just the right information at just the right time, day/night and all-weather, to provide situation awareness, threat assessment, targeting, and battle damage assessment. This means information fusion for true global presence. Total awareness of the operational environment will become a necessity for global presence and with it the knowledge of who and where the enemy is and where the friendly forces are. The end goal will be the omnipresent view of the battle field in real time in all weather. It will require continual world wide coverage of any location at militarily useful fidelity, in addition to exquisite fidelity of special areas for technical intelligence.

The U. S. needs to be prepared to fight wars in an environment in which the enemy has access to a high level and quality of battlefield navigation, weather, and situation awareness data. In this new environment dominance of information-based warfare requires control of space. We must develop and field the capabilities to protect U. S. and allied interests in space and to deny our adversaries similar useful support through investment in capabilities to deceive, manipulate and destroy. Passive and active protection measures must be taken for friendly space assets.

With continued proliferation of missile technology and weapons of mass destruction throughout the world there will be a growing threat not only to U. S. forces overseas and our allies, but also to the territory of the United States. This threat could be from ballistic missiles or cruise missiles launched by large or small powers who may not be deterred by traditional means. Surveillance and warning of these events and battle management can be effectively accomplished with space based sensors, and defense against these threats may be effected by space based weapons.

For the U. S. to sustain its superpower status it will become necessary not only to show global awareness through space based information, but also to be able to project power from space directly to the earth's surface or to airborne targets with kinetic or directed energy weapons.

Thus the application of space in future military operations will facilitate global presence, knowledge on demand, space control and power projection. This is possible with the continued improvement of space systems operations with reduced manpower at lower cost, design of spacecraft with modern low cost techniques, adaptation of innovative architectures incorporating small distributed satellite systems and above all the development of affordable access to space.

Conclusions and Recommendations

A general assessment of the future world environment and technological developments leads to conclusions and related recommendations for action by the United States Air Force. The recommendations are provided in the context and on the assumption that the Air Force will be the executive agent for DoD space matters and that the Air Force is prepared to assume the responsibility of supporting all military customers and national needs as required by the National Command Authority.

The overarching conclusions are:

- Successful integration of space with our information based warfare capabilities will be critical to maintaining information dominance of the battle space and winning at information warfare
- The proliferation of commercial space systems gives our adversaries unprecedented access to militarily significant capabilities that will reduce the information advantage our forces presently enjoy
- The Air Force must welcome and capitalize on capability growth and technological advances in commercial space in the fielding of militarily useful systems
- The need to disrupt, deny and influence the enemy's perception of the battle space while assuring our use for information based warfare is essential, and thus space control takes on new significance in this environment
- In the long term space systems will be well suited to project force from space to targets anywhere on earth
- Some near term program activities could limit efficient implementation of the future options envisioned in this report, and the Air Force should establish roadmaps to correct this situation

The Space Application Panel arrived at the following specific conclusions and recommendations:

Information Warfare

With the proliferation of commercial information sources the management of information and influence of the enemy's perception of the battle space through information warfare will be the dominant factor in deterring and winning future wars. Collection, fusion, analysis, disruption, disablement, denial and tactical and strategic deception of battlefield awareness are warfighter functions that must be integrated into our joint warfare operations to attain and maintain information dominance.

Recommendations

1. The Air Force should support integrated but dispersed processing and fusing of intelligence and battlefield awareness data to provide our forces the advantage of faster and more expert use of available information.

2. The Air Force should advocate the creation of a joint warfare information function to be in charge of all information that influences the outcome of the battle.

3. The Air Force should take the lead to define the space system requirements to support offensive and defensive information warfare.

Commercialization

Capability growth and technological advances in commercial space, especially communications, positioning, environmental monitoring and reconnaissance will far outpace government efforts in many areas. Customers, including individuals, corporations and nations, will have unprecedented access to militarily significant data that will reduce the "information advantage" our forces enjoy presently. These systems will be comparatively robust, secure and accessible as unique military systems.

Recommendations

1. The Air Force should develop specific road maps for the exploitation of commercial communications, positioning, environmental and reconnaissance systems that assure availability of these assets from day to day peacetime operations through major regional conflicts.

2. The DoD must develop, document and implement an approach to positively incentivize commercial providers of space-based goods and services to do business with the government and to add military-unique functionality to their commercial systems to give the DoD incremental advantage at lowest costs. The key is to establish relationships with commercial providers early in their development cycle.

3. The Air Force representing DoD should establish an integrated product team to: a) maintain a continuous assessment capability of commercial space systems and their supporting communications and ground infrastructures which may be potentially useful or threatening to the United Sates; b) act, or enable a clear path to higher authority to recommend action, as a result of these assessments; and c) infuse commercial technology/operational capability awareness throughout the relevant planning, acquisition and operational elements of the USAF.

4. The Air Force, representing the DoD, should establish much more effective mechanisms to promote regular dialog, alliances, and investment to interact/participate with US commercial

space enterprises in the areas of: a) standards definition, b) bandwidth/frequency allocation, c) joint specifications definition, d) joint development, especially for low-demand but cutting-edge technologies important to the US government, and e) operational control/access/privileges during times of declared national emergency.

Distributed Satellite Systems

Advances in computers, sensors, and materials permit establishment of large constellations of interlinked satellites, whose integrated output will give global, real-time coverage. Reducing range to target and constellation altitude reduces satellite size and cost of coverage. The advantages of such systems have already been embraced by the commercial space industry as the way ahead.

Recommendations

1. The Air Force should create a road map which recognizes the twin realities of inexpensive, single-sensor, small satellites and distributed processing and communications enables a significant advance in reconnaissance, surveillance and battle awareness.

2. The Air Force should begin development of a suite of small satellites to complement the evolving national sensors for timely battle field reconnaissance.

3. The Air Force should focus, where appropriate, on hybridized, distributed architectures, employing on-board processing, storage and cross-linking now being incorporated in commercial distributed space system designs.

Communications

Future multimedia communications systems will provide broadband communications to any person and to any point on the globe. These universal capabilities, whose transmission media and routing will be transparent to the users, will be available commercially and will provide reliability, flexibility, capacity, security and quality of service that will be difficult to match with government owned systems. Connections to other elements of the information systems may be more limiting than the communications systems themselves. Rapid expansion of use of available bandwidth due to advances in processing and antenna technology will significantly improve communications available to mobile users.

Recommendations

1. The Air Force should develop and implement a global terrestrial and satellite communications architecture whose infrastructure would be built upon both DoD and commercial capabilities.

2. Published standards should be established for future communications architectures to be distributed, flexible, scaleable, fault-tolerant, reconfigurable, and transparent to the users.

3. The Air Force should advocate the practice that DoD users who can reside on fiber optic arteries should be required to do so, and the warfighters given priority for satellite communications for mobile and tactical users.

4. Truly unique military survivable and enduring satellite communications requirements should be identified and implemented through a combination of unique military space systems, complemented with appropriate non-military systems and technologies.

Global Positioning, Time Transfer And Mapping

The current Global Positioning System (GPS) using the P(Y) code meets the present basic requirements of the military for precise position location and time transfer. The GPS employs the Defense Mapping Agency WGS 84 world wide grid permitting maps and data, such as derived from reconnaissance, to be expressed in a common position language for use as needed by the warfighter. The GPS user receivers when properly designed and integrated with Inertial Measurement Units provide highly accurate navigation in three dimensions to fast moving vehicles. Such military receivers are resistant to jamming especially when equipped with self-nulling antennas. The C/A code is available to all GPS user receivers. It thus can be used by potential enemies unless jammed in the battle area. The use of the Selective Availability concept has reduced international acceptance of the GPS for such civilian uses as commercial air navigation and proliferation of differential GPS has diminished its usefulness.

Recommendations

1. The use by the DoD of selective availability (S/A) to reduce the accuracy of the C/A code position location should be discontinued.

2. Methods and systems should be developed to assure U. S. and allied forces positioning information over limited battle areas while denying similar quality support to the enemy forces without seriously affecting essential out of area civil and commercial operations.

3. In the long term the Air Force should aggressively support advanced technology using space systems leading to consistent positioning and mapping accuracies on the order of 30 centimeters. Such space systems should support relative position accuracies in the centimeter range.

4. Time transfer to accuracies of a nanosecond or less should be an integral part of any global positioning system to provide synchronization in future communications and information systems. The highly accurate temporal and spatial information should be assigned eventually to all information and serve as the basis for the storage and retrieval of this information.

Observation And Battlefield Awareness

The information that can be obtained from space-based sensors integrated with airborne systems and geopositioning capabilities offer the potential for revolutionary changes in the combat environment and employment of forces. Future U. S. commanders must have near real-time, all weather information on the location and status of friendly and hostile forces; locations of moving ground, sea and airborne vehicles, and space objects; current and future projections on terrain and weather; nearly instantaneous threat warnings; and the ability to share this information with all levels of command.

Recommendations

1. In order to exploit fully the available technology to the warfighter's advantage, the Air Force should be a full participant in planning, developing, acquiring, launching, and operating of U. S. military and intelligence space reconnaissance assets.

2. Aggressive investment should be continued on methods and technologies to extract information from data at all points of the process. The focus should be on rapid, smart systems to reduce the dependency on humans wherever appropriate.

3. A user-needs driven attitude should prevail within the information acquisition community and a seamless interface should be established with the intelligence community to ensure sharing of data bases, and commonality of objectives. System, and architecture definition and implementation with full warfighter input, recognizing the need for balance among all users, technology and attendant costs should be pursued.

Space Control

Because of the general recognition of the importance of space systems to successful combat, we must assume our space systems will be threatened and it will be necessary to limit an adversary's access to space capabilities. Survivability requirements and techniques, against both hostile and natural threats, are as important for space system acquisition and operations as for terrestrial systems. A spectrum of offensive capabilities ranging from temporary disruption of hostile ground operations to satellite negation should be available to our forces. Local control of an enemy's environment, through disruption of his communications and information infrastructure, without global disruption will be an important tactic.

Recommendations

1. The Air Force must ensure that its most valuable space assets are safe against attack by third world nations, rogue groups and major powers.

2. The Air Force must develop and field a capability to deny, degrade, disrupt, exploit and, if necessary, destroy the use of space assets by others, globally or in a local region.

3. The Air Force should continue to study the potential threat posed by space debris and the necessary techniques for its surveillance, mitigation and removal, if necessary.

Force Projection

Future space systems will be well suited to project force against air, land and sea-based targets anywhere on earth. Precise delivery of munitions, directed energy or electronic warfare on virtually any target, heavily defended or not, within minutes or hours of tasking and with minimal risk to U. S. forces could have a decisive impact at all levels of conflict.

Recommendations

1. The Air Force should broaden the use of space to include direct force projection against surface, airborne, and space targets.

2. The Air Force should define and develop microwave and laser space-based weapons for tactical and strategic applications

3. The Air Force should develop space munitions capable of precision strikes against surface and airborne targets.

Access To Space

A number of commercial projects are underway to develop small and medium launch vehicles and there is strong competition from the international providers of large vehicles. Full integration of space capabilities into routine military operations will only be realized when launch is no longer a significant operational constraint. Although expendable vehicles may continue to provide limited, unique services, over time, dramatic improvements in cost and capability will come through an operational reusable system for all orbital regimes. The same technologies and operational concepts needed for reusable space launch will support transatmospheric systems that could provide presence anywhere on the globe in under two hours. Military human roles in space may evolve in time for on-orbit support of complex systems.

Recommendations

1. Continue to support the NASA reusable space launch technology efforts within the Air Force laboratories including the X-33 technology efforts but emphasize operability and reliability.

2. Continue to support a hypersonic technology development program with the objective of readying the technology base to support the development of future transatmospheric vehicles.

3. In conjunction with NASA continue to investigate the utility of humans in space for military operations.

4. Place emphasis on developing high specific impulse, high thrust propulsion technology to support development of future launch and orbital transfer vehicles.

Modeling, Simulation, And Analysis

Modern and future tools for connecting widely distributed centers of MS&A excellence and the explosive growth of virtual reality concepts and technologies will make it possible to conceive ideas and test them with technology, hardware and humans in the loop and then smoothly transition these experiments, demonstrations, and exercises into operations with unprecedented speed at heretofore unrealizably low costs. This is particularly true for the utilization of space systems. The Air Force should exploit these opportunities and the substantial investments in the National Test Bed to underwrite the development of doctrine, lower the costs of modernization, and train the joint warfighter.

Recommendations

1. The Air Force should quickly press ahead with a joint implementation of a DoD "virtual test bed" for space technical concepts and warfighting conops.

2. The DoD must eliminate the boundaries between MS&A for modernization support and MS&A for operations support. A seamless process which includes the joint warfighter in acquisition MS&A and the acquirer in operations support MS&A will be essential for rapid and cost effective reconfiguration of systems of space systems.

3. The Air Force, in conjunction with the Army, Navy, Marines, and others, should exploit virtual reality implementations to make space support more readily understandable to the political decision maker and the warfighter by allowing individuals to immerse themselves in the space-terrestrial operations continuum.

Space Applications to Warfighting and Related Issues

We must view our total force posture as an integrated warfighting machine of various space systems, aircraft, UAVs, ships, submarines, vehicles, ground stations and communications links. To reach this goal, the physical hardware and software must be defined, designed, built, tested and deployed. Thus it is necessary to examine the impact of the postulated future vision on individual elements and systems. The missions considered are: missile warning and space surveillance; global reconnaissance; communications; global positioning; time transfer and mapping; space control; and force projection. Each of these missions has a heritage from the past and their systems represent a substantial investment of funds, talent, infrastructure and operational experience. Current reality, projections for the future and the necessary changes to improve effectiveness and affordability generate a number of issues that deserve special examination. They are: space launch in the 21st century, use of commercial capability, international space developments, survivability of space systems, distributed space systems, and human role in military space applications. All of these mission and cross cutting issues are addressed by individual papers written by the various members of the Space Application Panel.

Abstracts of Issue Papers

Printed in Chapters 4 and 5

Imagery Reconnaissance and Battle Field Awareness

The USAF will be aggressive in working out an appropriate role in the U. S. dominance of the high ground of space not only for combat, but also for crisis surveillance of potential battlefields. The USAF should adopt a charter and vision which at least incorporates the following:

- A system-of-systems to collect, analyze, archive and disseminate information of importance to the warfighter. This should include at least weather, maps, imagery of possible battlegrounds, condition of roads, lines of communication, weapons types, precise location of friendly and hostile forces during combat, and numbers, readiness and organization structure of the probable adversary.
- An array of collectors, including manned aircraft, remotely piloted vehicles with loiter capability , with all-weather sensing capability, and either a permanent high orbit long-dwell capability, a constellation of single-function small satellites, or a launch-on-demand tactical satellite system with all-weather imaging capability to supplement and enhance the coverage of current systems.
- An open architecture to permit easy incorporation of technology advances in collectors, data storage and transmission, including all-source fusion methodologies, algorithms, techniques, and automatic and/or analyst-aided exploitation decision support systems as they become available, proven and affordable.
- An inherent ability to deploy the forward elements of the system to any part of the world on short notice and to be ready within minutes to pass desired information from all current and archival data bases to the deploying troops, systems and smart weapons.
- A strong and well-funded team to design, develop, acquire and operate the system with suitable assignment of responsibilities among the warfighters, the developers, and the global communications infrastructure.
- A policy of cooperation with commercial developers of systems and subsystems to ensure conformance with standards and availability of data throughout the development cycle, importantly including USAF understanding and potential denial of commercial imaging data to enemies or their probable allies.
- A seamless interface with the intelligence community to ensure sharing of databases, commonality of objectives, and straightforward cooperation during any transition from peace to crisis to conflict.

The Air Force must develop and learn to use effectively the triad of manned aircraft, UAVs and satellites for synergistic as well as complementary intelligence. The Air Force must move military user-level processing, fusion and exploitation down the chain from the centralized exploitation resource of a few ground stations and a few exploitation centers to the maximum dispersal and availability of archival information consonant with advances in computer distributed storage, processing and exploitation support and with the users' needs, including direct downlink to the battle area as appropriate. The USAF must commit to provide this information in the form desired by the user and in time for him to benefit from it.

Missile Warning and Space Surveillance

We now have a missile warning system based on radars and satellite short wave infra red (SWIR) sensors. The Defense Support Program (DSP) satellite missile warning system is the primary element but is based on decades-old technology using largely single band SWIR detection. It uses linear arrays of detectors scanning at a relative low speed with large pixels designed to produce adequate signal to noise ratio against large strategic missiles. Their main weakness is the scanning delay between revisits, which cause the system to miss transient events and take tens of seconds to establish tracks. Offsetting this is the Talon Shield ability to integrate the outputs of several satellites for stereo track reconstruction and the use of lower thresholding, which makes these satellites effective against order of magnitude smaller theater missile signatures and provides more accurate and timely tracks.

The Strategic Defense Initiative (SDI) with its initial objective of countering massive ICBM raids resulted in IR satellite designs using large focal plane arrays either scanning or staring with massive on board signal processing and computation. Attempts to use this approach for a DSP follow on has not met with acceptance. The present plan is a Space Based IR System (SBIRS) that contains a high altitude component in GEO and HEO orbits, a LEO flight demonstration system, and, assuming a year 2000 decision to deploy is made, a low element in LEO. The low altitude element will have sensors that could search below the horizon for missile launches as well as visible and MWIR sensors to track reentry vehicles and other space objects above the horizon. There is the nagging question of the need in the long term for both GEO and LEO systems since it appears both the missile warning and the midcourse tracking requirements of BMD could be done from LEO. The principal stumbling block with the LEO system is demonstrating the MWIR and LWIR capability to track RVs and space objects and the control of a relatively large number of satellites with an efficient satellite control system using minimal manpower.

The present space surveillance system is comprised of a number of ground sensors including radars and optical devices, some of which are in the United States and others are at foreign bases throughout the world. The optical devices include imaging, photo/polarimetric and conventional telescopes using electronic image tubes. The data from these devices are fed into Cheyenne mountain in Colorado Springs where orbital parameters are calculated for each of the cataloged items and sensor tasking is prepared and sent out to allow update of the space catalog.

The radars were generally built for other purposes and have inadequate calibration for this task. The optical sensors have marginal intrinsic resolution and dated focal plane technologies. Both are supported by dynamic models based on inadequate physics that have been ported from earlier computers and advantage is not taken of modern computer architectures or hardware. The result is an expensive and inaccurate surveillance system that is in need of change. In the long term, a space surveillance capability will be needed to search for objects that are more numerous, maneuvering, stealthy, and potentially hostile.

Communications

The communications capabilities of the future will include global person to person connectivity, high speed digital data, voice and multimedia, direct access to vast reservoirs of information, and enable virtual reality, computer simulation, rehearsal and event execution. These universal capabilities, whose transmission medium and routing will be transparent to the customers, will be available commercially and will provide reliability, flexibility, capacity, security and quality of service. The rate of technology changes will make it difficult to match these capabilities with any government-owned systems. There will be an explosion in data transmission capacity, made possible by major advances in fiber optics, microprocessor and antenna technologies, that will have a profound effect on doctrine, planning, tactics, organizations and where various functions are performed and by whom.

Major changes must be made in space communication assignments with respect to the current Milsatcom channel allocations. Those users that can reside on fiber optic arteries must be required to do so, freeing the capacity on orbit for use by the mobile, tactical users. There is a pressing need for a DoD global terrestrial and satellite communications architecture whose infrastructure could be built upon both existing and planned DoD and commercial capabilities. This architecture should embody the essential features of any architecture, i.e. seamless, open operating environment, "user-pull", multimedia, scaleable and multi-level security/trusted systems and be distributed, flexible, and reconfigurable. The infrastructure for this architecture will include commercial and DoD communication satellites in different orbits, in different frequency bands that are interconnected by cross links.

Massive on board signal processing should be a major factor in the design of future communications satellites to improve the signal to noise ratio and effectively increase the power output and ameliorate the power aperture problem for the mobile, tactical users with small antennas. This leap in processing capability will enable communications 30 to 40 dB and possibly greater, below the noise level, permitting users to operate on top of each other without interference.

There will be an ever increasing demand and competition for frequency spectrum, that will require wide use of frequency-reuse technologies and procedures, i.e. large numbers of simultaneous spot beams with extraordinarily small footprints, usage of higher frequencies (millimeter, infrared, and optical wavelength), etc. Soon one will be able to communicate via polyglot computers that will translate and provide language error correction for duplex communications with most nationalities in the world.

Global Positioning, Time Transfer and Mapping

The horizontal accuracy of the current Global Positioning System (GPS) was specified as 16 m and the time transfer accuracy as 100 ns. Actual performance in military user equipment has exceeded the specified performance by a factor of about two. Special civilian applications have developed higher relative accuracies. In real time relative position accuracy using ground reference receivers (differential GPS) can provide accuracy of better than 1 m. Post processing for surveying purposes yields accuracies of relative locations to 1 mm for each 10 km.

The GPS currently broadcasts two sets of signals - the C/A acquisition code and the P/Y encrypted military precision code. The C/A code is available to all users, military, civilian and commercial. The GPS with the C/A code is revolutionizing the movement of goods and people through out the world as well as improving world-wide digital communications, etc. By the same token, unless steps are taken to deny its availability to an enemy in combat areas, it can be used against the U. S. and allied forces in time of war.

An attempt was made by the Air Force to reduce the accuracy of the C/A code by deliberately introducing errors, a condition called Selective Availability (S/A). Differential GPS developments and wide area augmentation programs have essentially nullified the utility of S/A. In addition, S/A has reduced international support for the adoption of the GPS by the ICAO for world-wide aircraft navigation.

The anti-jam capabilities of the current GPS receivers depend on many factors, such as the signal strength at the receiver, the receiver design, the use of the C/A code, and antenna design. The use of the P/Y code and self nulling antennas provide a more robust system for the military. The P/Y code is broadcast on both the L1 and L2 frequencies, while the C/A code uses only L1. Since only the C/A code is generally available because it is not encrypted, the denial of the GPS to an enemy by jamming the L1 frequency use in the battle area is feasible. Such jamming may affect civilian use of GPS in peripheral areas requiring use of back-up navigation systems in the affected regions.

In the future many technical opportunities exist to improve the accuracy of information to the receiver. The signal strength at the receiver supporting the P/Y user should be increased substantially to further improve resistance to jamming. Cryptographic security can be improved by electronic key distribution. In the long run, overall system accuracy should approach 30 cm in three dimensional position, system time and time transfer accuracy will be 1 ns. The net result is mapping and target coordinates with highly improved accuracies allowing operations such as passive weapon system precision delivery against fixed targets with no requirement for terminal homing, more accurate reconnaissance and surveillance, Category III aircraft landing in unprepared fields, air-to-air refueling under all visibility conditions, and improved coordination of joint and combined operations.

Technological opportunities for improvement in future satellite navigation systems are available through: satellite and constellation design; receiver and antenna designs; as well as by improved integration into user systems. System designs which easily allow technology insertion will lower evolutionary costs and provide more robust capabilities.

Space Control

The totality of US spacecraft in orbit twenty to thirty years from now, military and commercial, together with their ground-based control nodes and launch sites will form a high value element of the national military capability. As such, it is likely to provide a tempting target set in the times of crisis, as well as a target of opportunity for rogue nations or terrorist groups intending to maximize the political and publicity benefit of tweaking the tail of a superpower. During the time period of interest, there will also be constellations of spacecraft operated by other nations and international consortia. Adding to the complexity of the situation expected to exist 20-30 years from now, is the likely presence of several, if not many, larger, manned space stations and space power stations. It may be in the national interest of the US to develop and deploy capabilities to disrupt, degrade or even destroy the space assets of adversaries with great precision and discrimination while also having the capability to protect U. S. national security and commercial assets by passive and active means.

The issue of space control—the sum of defensive operations to protect US military and commercial assets and offensive operation against adversaries, will require continuing attention to the survivability of space systems (and other space nodes) on the one hand and the capability for discriminate attack, electromagnetic or physical, on hostile space assets.

Total protection of space assets against a determined and technologically sophisticated adversary is difficult. However, a whole host of technological solutions currently exists which can, at least in part, protect space systems against cheap shots. The challenge is not to allow these technologies to atrophy or be forgotten during this post-cold war era, so that, at all times the nation's most valuable space assets are appropriately protected against physical and electromagnetic threats.

Commercial systems, current and particularly future systems such as Iridium, Odyssey and Teledesic, have inherent survivability of the space segment because of the numbers of spacecraft involved, excepting attack on the ground control nodes or nuclear detonations in space. A modest effort in selected survivability enhancement may be warranted for these systems as well.

Physical, electromagnetic, and laser attack as well as jamming of hostile space assets is currently technologically feasible and will become increasingly so as technology is developed. Space interceptor technology is well developed now and is likely to become increasingly affordable. Space surveillance capabilities and integration of several weapons system to provide the nation with an integrated capability for negation of spacecraft while avoiding collateral effects is likely to be the principal challenge.

The saturation of orbital positions at synchronous orbit, for example, is almost upon us. The physical and electromagnetic interference problems affecting space systems will become an issue, unless care is taken through international agreements to establish "rules of the road," zones of avoidance/exclusion, etc.

The launch rates and staging events to create the constellations of the future will likely drive up the debris population to the point that the probability of physical collision may exceed the probability of a mechanical or electronic failure on a spacecraft. This will require the rigid control of debris production and also the development of debris clearing procedures.

Force Projection from Space

In the next two decades, new technologies will allow the fielding of space-based weapons of devastating effectiveness to be used to deliver energy and mass as force projection in tactical and strategic conflict. This can be done rapidly, continuously, and with surgical precision, minimizing exposure of friendly forces. The technologies exist or can be developed in this time period. The resulting capabilities would include denial of air supremacy at will, defense against ballistic missiles, and ECM/ICM on demand, and could radically increase the cost-effectiveness of the US forces in future conflicts.

A first option for force projection from space would capitalize on advances in large, lightweight antenna technologies. These would result in antennas many hundreds of meters across, which will enable space-based electro-magnetic weapons with very high effective radiated power. These weapons would project very narrow beams with extremely high power density on airborne, surface, or space targets. A single spacecraft in GEO would suffice to continuously cover an entire theater with one beam, or form a number of beams to localize its effect within many footprints of only a few miles diameter each.

The energy density in these beams would greatly overpower and incapacitate sensors, receivers, and unprotected electronic equipment for extended periods, or burn them out. In addition it could provide surgically precise and overwhelming jamming or spoofing on demand, as well as introduce network saturation, disruption, and computer interference.

A second option is space based high energy laser weapons, which will become much more attractive in the future as a result of new technologies, such as 20 meter thin film mirrors used in conjunction with phase conjugation correctors, and lowered cost of access to space. These advances will enable lasers with reasonable mass and cost to effect very many kills compared to current concepts, and therefore they could be utilized against a large number of high value surface, airborne, and space targets. These laser weapons would be highly effective against strategic or theater ballistic missiles, and have a much more favorable cost-exchange ratio than previously considered concepts.

The commercial sector, responding to market forces demanding clean and inexhaustible energy, may develop megawatt-to-gigawatt level microwave beam power transmission systems in orbit, with several lower-power developmental systems. These could be adapted to beam large amounts of RF or laser energy to the space-based force projection weapons. Alternatively, dedicated power beaming systems could be built by the Air Force on the ground or in space. A power beaming capability would provide virtually unlimited power to space weapons, as well as greatly increase their delivered energy and useful life.

A third option for force projection from space can be created by recently introduced technologies that would permit extremely accurate delivery of long rods from space rapidly to anywhere on earth on command. These munitions would be precision guided and arrive at hypersonic speeds, penetrating hundreds of feet deep to destroy hardened bunkers. Alternatively they could home in on surface armor, aircraft such as AWACS, and other high value targets, also with complete surprise and devastating effectiveness.

Launch in the 21st Century

Today's expendable launch vehicles are derived from the ballistic missiles of the 1950s. All these vehicles require substantial on-pad time to check out the vehicle, ranging from 50 days for the Atlas to 110 days for the Titan IV and call up time to assemble and check out the vehicle at the launch base ranging from 98 days for the Delta to 180 days for the Titan IV. The Air Force would like the on pad time to be no more than 3 days and have the payloads shipped ready to launch as encapsulated payloads that conform to standard interfaces. These are all achievable objectives of a redesigned expendable launch vehicle with today's technology.

The Air Force is currently pursuing the Evolutionary Expendable Launch Vehicle (EELV) program. The concept is to replace the existing ELV fleet with a single family of expendable launch vehicles with common subsystems, and to achieve high reliability, low cost and improved operability. If the EELV program is continued to completion, it undoubtedly will be the expendable launch vehicle of the next twenty to thirty years.

Besides the long preparation times, these vehicles are expensive to procure and to operate. Typically the cost per pound for US launch vehicles is on the order of 4500 $/lb to LEO, and 10,000 $/lb to GTO, and 14,000 $/lb to GEO. The high cost of access to space has slowed the development of both commercial and military space. While the EELV has the goal of reducing the cost, order of magnitude cost reduction is only possible through reusability.

NASA contracted studies call for developing a full-scale conceptual design as well as developing a subscale Single Stage To Orbit (SSTO) reusable vehicle that can demonstrate the feasibility of the concept. In parallel critical technologies are being developed. The key issue is whether the technology can support true reusability, that is, refly with the minimum of servicing and not require recertification in the manner the Space Shuttle does. If this can be achieved a major part of the military space program, namely the medium class payloads, will probably be launched by the SSTO.

A key item that will have to be developed to support the future operations is the orbital transfer stage in that most military satellites are in orbits higher than LEO. If this stage is expendable it will add appreciably to the cost of operations. On the other hand if this stage returns to the SSTO and is recovered and returned to earth it may provide for lower cost operations if the infrastructure to support the recovery is not too costly of an investment.

Transatmospheric vehicles will ultimately come of age and be capable of carrying surveillance and strike missions anywhere on the globe in times measured in a few hours or less. These vehicles will be expensive and few in number, but their capabilities will make them a vital part of the future Air Force global capability.

The future of the transatmospheric vehicle lies with the enabling technologies which span material sciences and new propulsion systems, advanced passive and active thermal systems and high speed computational capabilities needed to control and configure the vehicle. Considering the scope and the needed progression of these technologies, a practical and operational useful transatmospheric vehicle is probably beyond the time frame of this New World Vistas Study.

Use of Commercial Capability

The current explosive growth of commercial digital systems for broadband communications, information and entertainment signals a rapidly increasing gap between these commercial systems capabilities and that of our military and intelligence communications and information systems. The development of these systems in the context of a business and consumer-driven market(high volume/ low unit price) ensures widespread global access and use to these capabilities.

In parallel to this remarkable revolution in information technologies , space missions are also becoming more financially appealing to the commercial sector. There has been a resultant increase in the amount of high resolution imagery, worldwide "cellular-type" communications, and commercial space-lift capabilities that are granting access to space for more and more nations. "Commercial Space" is simultaneously coming of age with "Information Warfare.

In the near term, it is clear that the relative benefits of this revolution will fall disproportionately upon our enemies in that access to worldwide advanced communications, computer processing and information and surveillance systems, previously denied due to the barriers of high entry costs or infrastructure deficiencies, will be assured. By the end of this decade, consumer broadband communications channels, desktop supercomputing power, processing software and widespread information sources, such as imagery and positioning, will be ubiquitous. Computing power in teraflops will be available on the desktops. Worldwide broadband communications will use direct broadcast satellites and new communications satellite constellations, such as Iridium. Proliferated positioning systems, such as commercial applications of GPS and GNSS, commercial imaging satellites, such as Eyeglass, wireless communications (28Ghz), and fiber optic communications networks are examples of the near future reality.

The US military can benefit from the commercial industry's profit-driven thrusts to reduce costs and streamline development costs for their space systems. This will be reflected in lowering DoD R&D costs, access to greater systems capabilities at lower costs and increased overall system robustness through efficient parsing of requirements between commercial and military-specific systems.

In order to reach this new world, the DoD must change the way it does business with commercial developers. New relationships must be built around greater interaction of DoD and industry partners early in the development cycle.

International Space Developments

The increasing worldwide availability of space technology and services applicable to military space systems portends a future in which military access to space is affordable, broad, and brokered through many global institutions. The development of appropriate and effective US space policy and the associated national security space system architecture must accommodate the internationalization of space as it significantly affects US military advantage from space. One of the more striking observations is the growing influence and probable dominance of the international commercial sector. Most of the international decisions affecting space development, including that of US military space, will be governed to a large extent by economic and business considerations.

The future of international space will be affected by, among other things, technology proliferation, the increasing influence and military utility of commercial space, increasing opportunities to access space to support foreign national security, and growing utility of space by foreign militaries. This is likely to lead to the enhancement of conventional foreign military forces, increased threats to US and allied space forces and a reduction in the global market influence of the US space industry.

The diffusion of space technology and related applications worldwide will continue unabated between friends and foes alike. This has fostered a more pervasive global understanding and exploitation of the commercial and military utility of space. Facilitating this process is a maturing international commercial sector that provides services via space and which has the ability to respond more quickly to changes in market demand and profitability than traditional military space programs. In addition, there are new players and their relationships to US sovereign interests may not be singular and stable over current planning horizons. The traditional roster of nation-state players must be reconsidered to reflect the geographically dispersed international commercial consortia, multinational corporations, allied coalitions and international criminal organizations. These new entrants will form complex technical and institutional interrelationships affecting the economics and utilization of international space.

More foreign militaries are incorporating space into their military doctrine and operations and are doing so more rapidly without having to re-trace the development steps of the US and Russia. There are increasing opportunities for foreign warfighters to obtain support from the international commercial space services sector as well as from new, dedicated foreign military space capabilities. In addition, the rest of the world has recognized the growing US reliance on space to support its warfighters thereby inherently increasing the vulnerability of US and allied space assets to foreign compromise. The potential is increasing for all international space systems to become targets as reliance on space services increases and enabling technology for counter space activities becomes more widely available.

The development of future us space policy and architectures must seek to exploit international opportunities to influence space support to warfighters, foreign and domestic. This might be accomplished through cooperative ventures with the commercial sector, linking technology export control and national space program objectives, and exerting positive control over technology proliferation. In addition, the global development and utilization of space must be constantly monitored by us space planners to ensure consistent and appropriate courses of action. This includes understanding the ramifications and threats posed by a growing reliance on complex international and domestic relationships providing critical national security space services.

Survivability of Space Systems

Erosion of previous inhibitions and diffusion of technologies will make survivability an increasing concern. Missile defense initiatives in the U. S. and the former Soviet Union developed and made public interceptor and laser technology. In the future, efficient rockets and kill packages suitable to attack satellites will be widely available. Interceptors can be cued by commercial optical systems. Signature reduction is possible, but difficult for satellites that can be observed over long periods of time from many angles. Visible or infrared search or occultation could suffice for detection and track. Such systems might be mounted for $30-50M. They could be manned by third world personnel. The availability of components, cost, and integration are not likely to be a significant hurdle to their development.

Large satellites can not out-maneuver interceptors. Decoys increase the number of targets interceptors face and force them to include more sophisticated discrimination sensors. But decoys take mass. Fragment warheads reduce the benefits of satellite maneuver. A 100 kg kill package could spread centimeter pellets over 100 m. If the attacker could reduce the satellite's maneuver distance to a kilometer, the penalty for survival through maneuver would increase to about the satellite's mass. Attrition attacks can exhaust satellite fuel and decoys over time, defeating its mission. Space mines are small, simple payloads which rest of the world countries might be able to put into space soon after they gain launch capability or access.

Lasers were previously large, expensive devices, whose beams were spread by atmospheric turbulence. Recent developments have removed these constraints. Lasers can now be scaled to lethal levels for a few million dollars with technologies that are compact and could be hard to find. Active systems can sense phase errors and correct them with active optics. The technology required is modest. It is being provided to U.S. and foreign astronomers for scientific projects. The astronomical community has adopted and improved them and shared them internationally.

Lasers track targets at the speed of light, negating the effectiveness of maneuver, and their beams enter space without penalty, which gives them a significant mass and cost advantage. Continuous lasers deposit heat and kill by melting structural members. Pulsed lasers vaporize material, produce impulse by recoil, penetrate surfaces, and break structural elements. Even if it were possible to block bulk damage, it would still be necessary to prevent sensor kill. Short pulses of even a few kilojoules could damage a significant fraction of an unprotected detector array.

Distributed systems promote survivability. Their degradation would be reduced only in proportion to the number of satellites lost. Flexible interconnection of the rest could make the overall system intrinsically survivable. The loss of one satellite would not even be felt for several days, and lost elements could be replaced quickly on demand with modest launchers.

Distributed Space Systems

Advances in computers, sensors, and materials permit large constellations of satellites with good sensors and communication, whose integration will give global, real-time coverage. Reducing range to target and constellation altitude reduces the size and cost of passive sensor and systems. The distribution of active sensors such as lidars, radars, and SARs over large constellations offers reduced, but significant, advantages. Staring sensors and space-based kinetic energy systems, which must cover the surface of the Earth at all times, benefit less, although distributing them minimizes response time.

Defenses benefit from the high spatial and temporal resolutions of distributed systems. Missile warning from distributed systems with advanced detector arrays and active sensors would be better, cheaper, and more survivable than current systems—and would have growth potential for aircraft and cruise missile detection. Global surveillance requires very high temporal resolution. Tens of satellites can produce resolutions of meters and revisit times of minutes. They offer an inexpensive way to fill the current gap in wide-area surveillance with quality information.

Distributed sensors and on board processing can perform instantaneous damage assessment, moving target detection, and missile launcher detection and track. All would be enhanced by distributed lasers, radars, and SARs, which can also detect chemical and biological weapons as well as current cloud distribution, composition, and winds at all altitudes. Distributed communication could make thousands of voice-quality circuits available in theaters, solving the "last mile" distribution dilemma. Distributed constellations have the potential of forming a coherent high gain communication arrays for electronic intelligence, jamming, communication to besieged or covert groups, or precision positioning. High capacity cross links can provide real-time, high-quality information and discrimination support, effectively projecting man into the battlefield.

The current sensor state of the art is represented by the visible and infrared cameras and lasers developed for missile defense. Current systems use megapixel arrays in cameras weighing a few kilograms, consume a few watts of power, and produce images with meter to tens of meter resolution. Laser capabilities have increased to hundreds of watts within tens of kilograms. They provide spatially and temporally resolved measurements of water vapor and temperature constituents. Adding to commercial communications systems offers synergisms and opportunities for cost savings. There is a sound technical basis for DoD/civil/commercial cooperation. The key enabling technologies are the ability to affordably build, launch, and control small spacecraft, whose key elements are the application of industrial methods for producing and operating spacecraft. Continued progress in computers, megapixel visible and infrared arrays, lasers, SARs, microwave sounders, lightweight apertures, and kinetic energy will lead to important new capabilities.

Human Role in Military Space Applications

Global presence beyond the 2020 time period may well require direct participation of the Air Force personnel operating in space rather than relying entirely on remotely controlled systems as is now the case. The unique Air Force interests in supporting DoD space assets can not be abdicated to other agencies, countries, or commercial ventures. The Air Force must be prepared, when appropriate, to directly utilize manned space capabilities to support the DoD overall space mission.

In the mid 1960's the Air Force initiated the development of a Manned Orbital Laboratory (MOL) which was to have operated in low earth orbit for classified missions. The program was canceled before MOL became operational for various reasons, including budgetary, political, but primarily because of parallel development of similar unmanned capabilities that required substantially less supporting infrastructure. In the years since the MOL was canceled considerable experience has been gained in manned systems including the Apollo missions, the very successful Skylab and the Space Shuttle missions which have included the Spacelab missions and various special purpose missions such as the repair of the Hubble Space Telescope.

As we look forward into the future we can envision a mix of military satellites including small distributed systems and large platforms that may require assembly in space to accommodate launch by the then existing space lift capability. In order to achieve affordable and cost effective operation we may need to view these platforms as we view aircraft today. That is, the platform (airframe) may have a life of 10 or 20 years or more and in order to keep it up to date with the latest technology we will need to upgrade the subsystems as we do with aircraft. This may require that the Air Force have a manned space capability to assemble, maintain, and to change out modules and subsystems on future space platforms. This defines two broad areas that need attention, the man peculiar techniques and equipment for servicing and the design approach to the platforms and subsystems to assure future space platforms can be efficiently and timely serviced.

A key component in the supporting infrastructure will be the orbit transfer vehicle to move crews and equipment from the space lifter vehicle to the platform to be serviced. It is assumed that in the time frame of interest, NASA and commercial interests will have developed solutions to this problem, but the Air Force will need to adopt what ever capabilities that exist to the DoD mission and purpose.

In the immediate future the Air Force needs to maintain close liaison with NASA on the space station design and operation and develop guide lines and doctrine as how they might utilize and support future space platforms and missions. As part of this activity technology objectives can be identified so that future technology investment can advance the Air Force's mission in this area.

Modeling, Simulation and Analysis

Modeling, Simulation and Analysis (MS&A) of space capabilities and the integration of those capabilities into terrestrial operations and the overall force structure is extremely partitioned. This situation is antithetical to advancing the application of space capabilities to joint warfighting. The SDIO, through its National Test Bed, spearheaded the concept of interlinked MS&A which could be used to demonstrate technical and operational concepts well before substantial hardware investments were necessary. The concept remains valid.

The concept was extended by the Air Force to include—military, intelligence, civil, and commercial space stakeholders. The concept was expanded to support decision making through experiments, demonstrations, and exercises with technology, hardware, and humans in the loop. The AF concept was named Frontier Arena and focused on exercise support in the early phases and then to provide support to DoD level modernization decision-making by enabling warfighter in the loop alternative assessments.

Ultimately, Frontier Arena may be used to evaluate tactics, operations, and strategies involving the integration of space and terrestrial capabilities. By linking space and terrestrial MS&A capabilities in a shared environment where each stakeholder can take advantage of the whole. Frontier Arena or something like it is essential to maturing our thinking about space and space related terrestrial issues.

Beyond Frontier Arena, virtual reality implementations offer the opportunity for political leaders and warfighters to visualize the interaction of all force elements—lethal and otherwise. Within the horizon of New World Vistas it will be possible for military officers and their civilian leaders to stand in the middle of a virtual theater and conduct digital sand-table maneuvers in multiple dimensions—space, time, and consequences. Commanders will be able to design their operations, test them, deploy the orders to the forces, and evaluate the results and required changes in one continuous intuitively visualized environment. Such a concept will put us inside our adversaries political, military, and economic turning circles for decades to come.

The Air Force plan for the joint implementation of Frontier Arena is fundamentally sound. It represents the first step on a path to command situation awareness previously only in the province of the futurist or science fiction writer. The Air Force is particularly well suited to lead such an enterprise and should commit to do so on behalf of the DoD.

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1.0 Introduction

1.1 Purpose

This Space Application Report is a part of the Scientific Advisory Board's response to the challenge by the Secretary of the Air Force and the Air Force Chief of Staff to "search for the most advanced air and space ideas and project them into the future."

The Space Application Panel's charter was to:

- Define space applications which enhance the intrinsic offensive and defensive capabilities of the Air Force
- Project system concepts and operations that will offer fundamental improvements and reduce costs in military operations
- Identify those areas which will most likely revolutionize the 21st century Air Force
- Consider the use of commercial and international space systems to support military operations and the impact on United States security from proliferating technology
- Recognize the Air Force responsibility to support warfighting as well as national customers and integrate operations with other services and agencies

1.2 Assumptions

Several key assumptions and scope definitions were made at the outset of the study:

- The Air Force will be the designated lead service for DoD space matters
- NASA will continue its role of scientific space exploration and research as well as human space flight
- Assume technology readiness for near term systems in 2005 and use reasonable technology projections beyond
- The *New World Vistas* Space Technology Panel will provide an assessment of technology readiness and interfaces with other technology panels
- National and DoD policy will evolve to underpin the proposed uses of space.

1.3 Process

The Space Application Panel consisted of members with extensive experience in military space matters who have participated in numerous military, civilian and commercial space programs and future studies. A number of information gathering sessions and visits were held between March 1995 and July 1995 as well as discussions with prominent military and industrial space leaders and CINCs. Inputs were received from the warfighter community and the National Reconnaissance Office. Several sessions were held with the Space Technology Panel to interchange ideas on trends and concepts. Also coordination was accomplished with the Sensor, Information and Attack Panels.

The space medium is special because of the physical characteristics of orbital mechanics; nevertheless, the use of space by the armed forces is embodied in the general principles of war like all other elements. All important is the use of space in support of the terrestrial warfighter as part of a joint force to accomplish the full spectrum of military tasks required by the National Command Authority. While at the present space is an essential element of supporting global awareness, in the future the use of space will lead to the full realization of global presence through power projection from space.

The Space Technology Panel has taken the applications considerations from the Space Application Panel for the near and far term future and elaborated on the necessary technology investments to support the common vision. The Space Application Panel has concentrated on projecting future military space operations as derived from the principles of war and applied to the needs of the warfighters and national authorities. These matters are treated in Chapter 2 on Insight and Future Vision and Chapter 3 on Warfighter Space Mission Needs.

The Panel examined a series of issues that pertain to the current situation and potential future developments. It chose to address future space applications by means of a series of issue papers which form the body of this report. These papers were written by members of the Panel based on their own experience and expertise. It was not attempted to form a consensus among all Panel members as to the statements in each of the issue papers. The Panel as a whole, however, has carefully discussed and formulated the conclusions and recommendations found in the Executive Summary and Chapter 6. They are based on material found in the issue papers printed in Chapters 4 and 5 as well as discussions or inputs received from other sources during the course of the study.

Chapter 4 on Space Missions and Their Applications to Warfighting is not merely a description of the current or projected systems, but an analysis of the needs and constraints imposed by the conflict of military mission needs and the realities of the international commercial market place on dual use systems, as for instance the dilemma that the remarkable success of the Global Positioning System presents. In addition, Chapter 5 contains a treatment of special Space Application Issues such as access to space, commercial space, distributed space architectures, survivability and the role of the human in military space flight.

2.0 Insight and Future Vision

2.1 A Dynamic World

We live in a dynamic world, an era of contradictory trends shaped by two great forces, one strategic, the other technical—the advent of the Information Age. The scale and pace of recent change has made traditional means of defining future military operations inadequate. In the absence of a relatively fixed, strategic environment, we are faced with a far more complex world that defies authoritative forecasts of the future.

Absent a reversal in Russia, there is now no credible near-term threat to US existence. That fact does not mean the nation's vital security interests will go unchallenged during this period of great strategic reordering. As a result US armed forces will remain fully engaged throughout the world, meeting the nation's security needs and helping shape what will prove to be a very fluid future environment.

The types of military operations we have experienced since the end of the Cold War will continue well into the decades of the twenty-first century. During this period the military will be called upon to defend and promote national and collective security interests throughout the world, often on short notice.

2.2 Future Challenges

In addition to strategic challenges, other challenges are associated with entry into the Information-Age. Information technology will make a thousand fold advance over the next twenty years in terms of the volume, speed and the number of individuals accessed by the global flow of information. Developments in this area have begun to revolutionize—how nations, organizations, and people interact. The rapid diffusion of information enabled by these technological advances challenges the relevance of traditional operations. Most importantly, that commercial technology is not necessarily easily available to the US military, and an adversary is not constrained by our slow approach to the acquisition and use of modern information systems technology can buy that technology off the same shelves we can—and use it to get inside our "turn radius", or information cycle.

Future information technology will greatly increase the volume, accuracy, and speed of battlefield information available to commanders. These technologies will allow organizations to operate at levels their adversaries cannot match, while simultaneously protecting their own capability—this is called information dominance. Information dominance is a relatively new concept, one that is moving to occupy center stage in our thinking about modern war. Information dominance of the battlespace and winning at information warfare will be critical to successful joint and coalition military operations.

2.3 The Nature of Space

Space, as the ultimate high ground from a military standpoint for broad area reconnaissance, surveillance, and communications will be critically important to information dominance. It is substantially different from the air, land and sea mediums because it is global by nature. Space is fundamental in achieving global presence, global reach, and global force and we must learn

how to efficiently manage our space assets consistent with rapid technology evolution and shrinking resources.

Air, land and sea are mediums of local equilibrium, that is, the force of gravity is repelled by local point forces acting on the body. In the case of air, land, and sea locally generated interacting force are required to control the vehicle and continuing expenditure of energy is required to keep it moving.

In orbit, gravitational force is in equilibrium with centrifugal force of the spacecraft, thus it is not dependent on the local medium for its support, but on global forces. Since in space we are operating outside of the sensible atmosphere we need to expend essentially no energy to maintain forward motion, however, position is not instantaneously at the will of the operator as is the case of air, land and sea. In order to achieve the necessary velocity to reach it, it is necessary to expend a large amount of energy initially, the problem of the booster rocket. As a consequence large expenditures of energy are also required to change the orbital characteristics. Also because space is remote and difficult to access, maintenance and logistic resupply are generally not available. The space environment is hostile in the sense it is a vacuum with large swings in temperature as the spacecraft is exposed to the sun and then the shadow of the earth. The region of space in which spacecraft operate contains high energy and particle radiation in the form of x-rays, gamma rays, electrons, protons as well as meteorites and space debris.

The space age was essentially ushered in by the Soviet launch of Sputnik in October 1957. This event awoke the United States to the national importance of being the predominant power in space. The National Aeronautics and Space Act of July 29, 1958 created NASA and set the stage for President Kennedy to declare the objective of putting a man on the moon by the end of the decade (1970). The Apollo program met this objective and demonstrated our preeminence in space.

Military space was also driven by the Soviets, first by the need for gathering intelligence and then from surveillance of their nuclear missile forces—our very survival in the nuclear age dependent on our ability to know the real capabilities of our adversary. The space program was initially directed at strategic considerations such as acquiring intelligence on Soviet capabilities, developing target lists, providing ballistic missile attack warning, and communicating to fixed ground terminals. Tactical considerations were a distant second in terms of expenditure of funds and effort until the third decade of the space age when systems such as GPS came into being. Exploitation of overhead reconnaissance data was initiated with TENCAP, but it took the Air Force almost ten years to fully get aboard the program. Space was considered from the strategic view point rather than an every day asset of the warfighter.

Military space is an outgrowth of the ballistic missile programs. Space boosters were slightly modified missiles and some of the first spacecraft were designed to acquire data on the space environment and re-entry physics to support the missile programs. Initially spacecraft were fairly small, somewhat experimentally built, the technology was immature and failure was not an unusual event. As time went on requirements on satellites grew, particularly from the survivability standpoint, and they became bigger, heavier and, of course far more costly.

Today's satellites are highly reliable with multiple redundancy and generally pushing the state of the art in mechanical and electronic technology at the time of design. The cost of space systems has grown from several hundreds of millions of dollars, to programs in excess of ten

billion dollars (Milstar). The weight of satellites has grown from less than a thousand pounds for GEO satellites, to satellites exceeding 10,000 pounds. For LEO the bigger satellites are on the order of 40,000 pounds.

Our proud heritage in space in space was born out of the ballistic missile and space races with the Soviet Union with national prestige and survival at stake. All along the way space was the domain of technologist and the "Big" user. Size, survivability, sensitivity, redundancy were absolutely not to be traded.

Desert Storm changed all this and proved the value of space in modern warfare. GPS derived data was used extensively to support ground, sea and air operations. The demand was so great that 15,000 commercial receivers were procured for use by the military. Weather data was largely supplied by satellites as was much of the long haul communications using both commercial and defense satellites. Imagery and electronic order of battle information was available, and DSP data was used to determine Scud missile tracks to alert Patriot air defense batteries and support counter air strikes against the launchers—although with no success.

While Desert Storm demonstrated the value of space to the warfighter, it also demonstrated the need for far greater responsiveness in terms of coverage, timeliness, and content. The value of getting the right information to the right place in time to really make a difference for the warrior has been established. What remains now is to reevaluate the military use of space in its full context as an essential element of the entire military force structure.

2.4 Space Applications Evolution

The collapse of the Soviet empire has created a substantially changed security environment. While survival is no longer at risk as during the Cold War, threats to the vital interests of the U.S. and its allies can be created by a number of power centers, including narco-terrorists or extreme ideological groups. Fueling this increased threat is the proliferation of weapons and expertise available globally. Complete weapons systems or their components are available from virtually all arms producers. Whatever one's politics, arms are available. Of key concern is the disposition of the massive weapon inventory held by countries of the former Soviet Union. A primary threat to U.S. interest stems from the marriage of even modestly capable military forces, with the expansion in the commercial availability of space resources and sophisticated consumer electronics technologies applied to weapon systems. The international commercial space markets are now providing both products and systems for communications, position/navigation, weather, reconnaissance, surveillance, and remote sensing. Other countries also understand the lesson of Desert Storm, and in particular, the force multiplier effect of space systems. Proliferation of cheaper launches and availability of satellite technology encourages potential enemies to use space as a force multiplier, and to consider measures to negate U.S. space systems. Information-based warfare is emerging as the dominant form of war, and future wars, whether local, regional, or global, will be won by the side winning the battle for information dominance.

One issue that will continue to constrain space applications is the cost and difficulty of space launch. No fundamental breakthroughs in propulsion technology are foreseen in the near future in any studies conducted to-date. While incremental changes promise some improvements, we have to accept for now the limitations in space launch. However, advances in micro-electronics and sensors are leading to order of magnitude changes in satellite size and capabilities, leading

to much smaller more operationally friendly or more economical launchers to achieve similar mission performance.

The U.S. currently has a clear technology lead that must be maintained. The current U.S. space force structure consists of systems that can cover the entire earth and thus provide global presence not possible with terrestrial forces. Having friend and foe alike know that we know what is happening is a deterrent capability of immense proportions. However the U.S. current dependence on large expensive systems has several weaknesses. They are inflexible, not responsive to mission changes, and when they become critical to mission success they will become points of vulnerability.

U.S. military space planning will be affected by realities of the rapidly expanding markets, both national and global. Commercial products are developed much faster than military products. For example, the GPS receiver development cycle dropped from 44 months to 5 months. Computer new product cycle time is down to 18 months. Due to this rapid development cycle commercial electronic products contain more recent and often higher technology than their military counterparts. Commercial high technology products have a short half life due to technology advances. They are highly reliable during use periods, and system longevity is not a factor due to rapid replacement. This is a key issue in the development of the new low earth orbit communications systems. What should the satellite design life be? U.S. military systems become quickly obsolete if developed under the current DoD acquisition cycle. The U.S. can no longer control proliferation of systems, technology, or expertise. International systems are now developing without U.S. participation. Opponents may be able to acquire military systems inside our development cycle, as technology and expertise are widely available, as well as greater understanding of space systems technology leading to better countermeasures. The U.S. may face a situation where an adversary may have sufficient high technology systems to create problems for the U.S., yet be "underdeveloped" and less vulnerable.

Developments in commercial space globally will revolutionize military space by providing the capability to fully implement information based warfare and exploit the compression of time in military operations. We need to understand the implications of these changes and how the military can benefit from them. The key question to answer is - what is the right mix of dedicated military and civil/commercial systems, and how to integrate them to support the warfighter?

Commercial space can help the U.S. military maintain information dominance in the 21st century by some combination of purchasing products, buying systems, or use of commercial components. In Desert Shield/Storm, the U.S. purchased products from a number of U.S./Allied commercial space systems. This included 350 communications circuits from over a dozen carriers; used civil weather data; purchased 189 Spot images; Landsat imagery was used extensively; and government, as well as individual purchase and use of commercial navigation receivers were one of the wonder stories. The GPS success has created an international political dilemma on how to satisfy the needs of both the commercial and military users in a dual use system. The international pos/nav community does not want to become dependent on a U.S. military system that may be denied. This concern is reflected in Inmarsat discussions on developing an international system, Europeans looking at GNSS, and other regional systems.

Commercial low altitude communications satellites will rapidly proliferate as both the big and little LEO systems (six different constellations proposed, e.g., Iridium, Teledesic, etc. as shown in Figure 2.1 Proposed LEO Communications Systems) become operational in the late 1990's providing a massive redundant, and survivable communications network available to the military.

Overview Of Proposed Leo Telecommunications Satellite Systems (> 1 Gh$_Z$)

	COMPANY	# SATELLITES	ORBIT/ ALT	ORBIT/ INCLINATION	FREQ	WT	COST	IOC	REMARKS
TELEDESIC	MICROSOFT (GATES)/ MCCAW	900 (40+4 IN EACH PLANE)	700 KM	21 PLANES 98.2° SUN SYNC	Ka Band 20-30 GHZ TDMA	750 KG	$15B	2001	Telephones broad band to remote areas & dev. countries. Packet Switching Network
IRIDIUM	MOTOROLA, LOCKHEED	66 (+7 SPARES)	780 KM	6 PLANES/ 11 EACH	L-BAND TDMA	700 KG	$3.4B	1998	Worldwide digital, cellular PCS. Russian & MacDac booster
GLOBAL STAR	LORAL QUALCOM& SPACE SYS.	48 (6X8) (+8 SPARES)	1390 KM 47%	8 PLANES 52°	16-25 MHz CDMA	400 KG	$1.8B	1997	Worldwide cellular voiced data & RDSS
ELLIPSO	ELIPSAT CORP./ WESTINGHOUSE FAIRCHILD	14-18 SATELLITES	2,900 KM X426 KM	ELIPTICAL 63.4°	L-BAND CDMA	175 KG	$650M	1998(?)	Mobile voice & RDSS for US
ODYSSEY	TRW	12-15	10,354 KM 55°	55° 3 PLANES 4 SAT	S&L CDMA	?	$1.3B ($52M/SAT)	1999	Voice data paging, msg.
CONSTELLATION (FORMERLY ARIES)	CONSTELLATION COMMUNICATIONS, INC. & DEFENSE SYSTEMS	48 4X12	1,000 KM	4 PLANES; CIRCULAR	16-65 GHZ S&L BAND CDMA	?	$300M ($1.5M/SAT)	1994 (FOC 1996)	Low-cost RDSS for US. OBEX launch vehicle

Figure 2.1. Proposed LEO Communications Systems

The U.S. military can buy commercial systems or be a user of commercial services. Satellite commercial reconnaissance systems are proliferating, e.g., 1 meter imagery systems are being offered by three U.S. companies. The U.S. operating commands may choose to buy, lease or use services from commercially available systems cheaper than they could develop one for military applications. Commercial software packages having requisite capabilities are available for a wide array of activities. The ground segment is also commercially available, ranging from COTS ground stations to portable antennas. Commercial enterprises can provide launch services to support surge requirements or to provide routine launches

The key military requirement is to assure availability of space support, whether by owning, leasing or using commercial system services, through CRAF-like arrangements with the ability to invoke national priority during times of crisis. Although CRAF concepts may work during times of unambiguous national emergency, it is not clear how these arrangements will work during military operations of lesser nature, which are expected to be the more prevalent situation.

2.5 International Developments in Space

New space powers are emerging. This trend is accelerating due to the proliferation of capabilities occurring globally, to include: 1) space technology, both as a commodity, and through classic technology transfer; expertise; systems; and through technical training and education. Foreign nations, particularly European nations and Japan, have targeted space as an area of strategic importance to their economic future. This is also one of the few areas where China, Russia, and other former Soviet republics can field technologies capable of competing on the world market. Eight countries currently, with another seven countries that are either actively developing, or planning to develop a national launch capability. Eighteen countries can build satellites, and 20 own satellites. Also 15 international consortia and joint ventures are currently flying. This widely available space launch system capability translates into a proliferation of systems available for foreign military space applications. These include:

Launch Systems. Over 50 launch vehicles are currently in with 20 more just for LEO payloads (Figure 2.2 New Launchers Under Development For Leo Orbits) under development. This does not include the various space launchers derived from ICBM/SLBM launchers, as proposed by U.S., Russia, and Ukraine. Although it may be more cost-effective to buy launch services, many countries will develop their own capabilities for a combination of reasons, to include national security, prestige, the development of an indigenous industrial base, and ensuring that they are part of the wave of the future. Russia is offering cheap launch services, with the START vehicle quoted at $2M. Russia is also offering converted ICBM/SLBM launchers for cheap rates. The presence of an abundance of cheap launchers for small satellites to LEO/MEO may have the effect of developing a market for such satellites and accelerating acquisition of space capabilities by other aspiring nations.

Communications. The satellite communications industry is the most mature of all space industries, with most of the present and almost all of the emerging space communications systems are owned, built and launched by multinational consortia.

Positioning. Eight commercial companies are providing or advertising a global differential GPS service; INTELSAT is discussing development of an international system for the commercial market and European nations are discussing a regional system called Global Navigation Satellite System (GNSS). While some countries may be willing to depend on an international provider, it is highly likely other countries will develop their own pos/nav capability. Technology is available to do some fairly cheap systems in a region.

Early Warning. France, Saudi Arabia, WEU., Turkey, and Japan have expressed interest in space based early warning capabilities, and this number can be expected to grow as the ballistic missile threat increases. While many countries would be content to depend on some type of alliance consortium, many will want their own capabilities.

Reconnaissance. Ten countries have remote sensing systems, and the number will grow (Figure 2.3 Commercial Imagery Market). France, Italy, and Spain have collaborated on Helios 1A, Germany may participate in the $2.1B Helios 2, although Lockheed has offered Germany a 1 meter resolution satellite at 1/5 the cost of Helios 2 (~$400M). Germany is expected to take the lead on developing an imaging radar spacecraft, designated Osiris/Horus, at a cost of $2-3 Billion. A rapidly growing market is developing for products with Russia offering 2 meter optical and 5 meter SAR, and a number of other countries offering similar products. Three U.S. companies

Company Name	Launcher Name	Payload	Orbit	First Launch	Price	Status
Orbital Sciences Corp.	X-34	1,500 lb	100 n.mi., 28.5°	scheduled for 1998	$4-6 million	contract award 1995; in development
Lockheed Martin	LLV-1	1,750 lb	100 n.mi., 28.5°	2nd quarter 1995	$16 million	launch imminent
	LLV-2	4,000 lb	100 n.mi., 28.5°			
	LLV-3	8,000 lb	100 n.mi., 28.5°			
	Multi-Service Launch System		100 n.mi., 28.5°			in development
AeroAstro	Pac-Astro PA-X	225 kg	suborbital	late 1996	$1.6 million	in development
	Pac-Astro PA-1	1,150 kg	suborbital	1998	$6-7 million	in development
	Pac-Astro PA-2	250 kg	100 km			in development
	Pac-Astro PA-3	1,450 kg	1,000 km			in development
CTA	Orb-X	425 lb or 885 lb (polar or equatorial)	400 n.mi. polar or 200 n.mi. 28.5°	no date	$8-10 million	on hold
	Start	1,000 lb	400 n.mi. orbit	no date	$8-10 million	on hold
E'Prime	Eagle	3,000 lb	200 n.mi. circular	1997	$10-35 million	seeking financing
	Eagle S1	6,000 lb	200 n.mi. circular	1997	$10-35 million	seeking financing
	Eagle S2	10,000 lb	200 n.mi. circular	1997	$10-35 million	seeking financing
EER	Conestoga	1,910 lb	250 n.mi., circular	July 1995	$25 million price to BMDO in 1992; $18-19 million quoted today	launch imminent
Eurockot, Daimler Benz	Rockot	1,000-2,000 kg	500 km	Mid 1997	No price available	in development
Amroc	Aquila series Aquila A	1,000 lb	199 n.mi., 28.5°	No date set	No firm price; touted as low cost	on hold
	Aquila series Aquila B	3,000 lb	199 n.mi., 28.5°	No date set	No firm price; touted as low cost	on hold
	Aquila series Aquila C	4,000 lb	199 n.mi., 28.5°	No date set	No firm price; touted as low cost	on hold

Figure 2.2. New Launchers Under Development For Leo Orbits

are offering systems with 1-5 meter resolution, and six commercial systems have been licensed, with two more applications pending. Russia has offered several of its reconnaissance satellites for sale, and other countries are entering the competition. Ukraine is offering an advanced ocean monitoring spacecraft (OKEAN-O) which provides multi-spectral, optical radar and micro-wave systems.

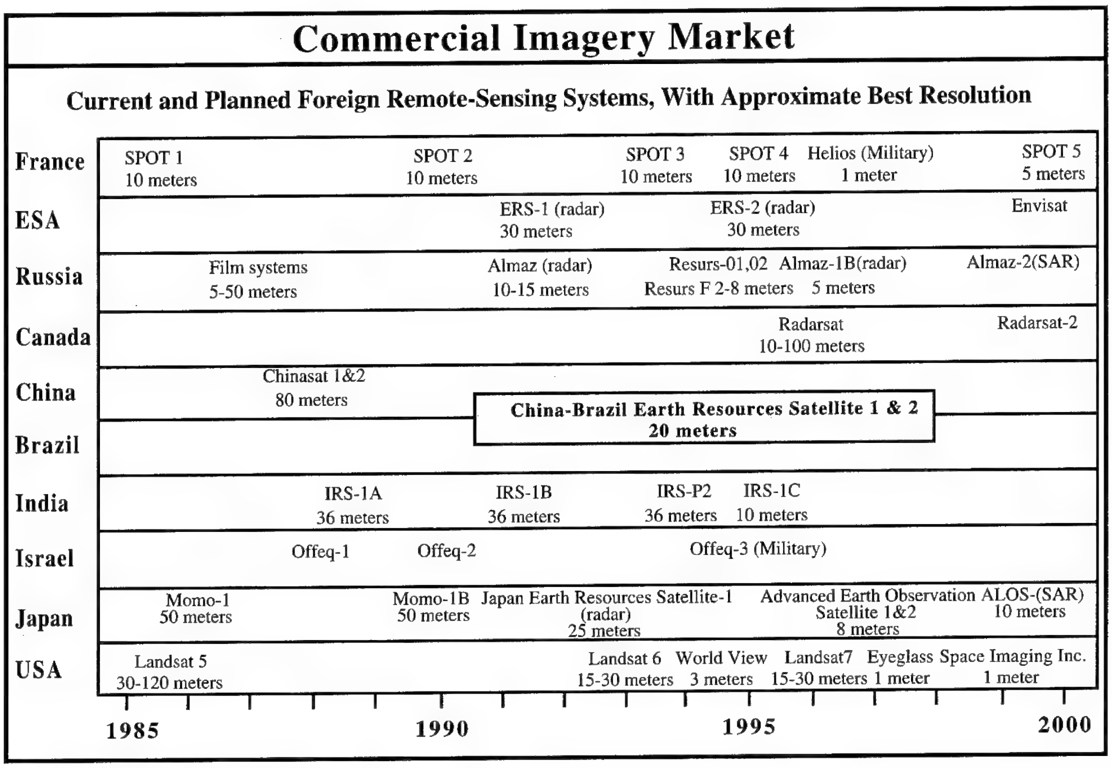

Figure 2.3. *Commercial Imagery Market*

Environment. Most countries will depend on international space weather data to supplement their ground based weather prediction capabilities. For example, the Europeans formed EUMETSAT, composed of 17 countries, and Canada is deploying a radarsat.

International Interdependency. International cooperation will increase, especially among the "have-nots." Consortia based on alliances to provide needed capabilities can be expected to increase. Increasingly complex international relationships in space are likely, providing global access to space and a broad spectrum of players. For example, U.S./Russian cooperation is continuing and broadening to include, not only the Shuttle/MIR activities and international space station, but also cooperation in launcher developments, and the use of Russian rocket engines on U.S. and other international launch vehicles. European/Russian cooperation is continuing and broadening, with Russia evaluating European advanced cryogenic engines. Future U.S. space applications must accommodate this emerging cooperation in international space activities. This will include providing support to warfighters by exploiting international and

civil sources of technology and services; the need for space control, some elements driven by national interests, others derived through international cooperation or alliances; and an uncompromising objective of maintaining U.S. global leadership in space.

At the same time, a proliferation of threats to U. S. space interests will evolve and would come primarily from primitive and not-so-primitive ASATs. Any country that has, or can build, a ballistic class missile can place any U. S. satellite in LEO (< 500 Km) at risk. However, to place a satellite at MEO (> 1500 Km) at risk requires an ICBM class booster, and even higher orbits require an SLV. Furthermore, there is a significant difference between attacking one or two satellites to achieve a political objective, and conducting a militarily effective campaign over time.

Other threats such as Directed Energy Weapons, High Power Microwave Weapons should be of little concern in the foreseeable future, except for threats from electronic interference. Other than a recovered Russia, no nation is likely to have developed sufficient capability to be able to gain control of space, although a number of countries, either industrialized, or those with sufficient money to buy sufficient ASAT capability may be able to cause damage.

A growing issue is the increased dependence of the U.S. on foreign suppliers of space system components and launch services. The threats to the ground segment also must be considered, but prudent planning to provide an adequate combination of security, defenses, proliferation, hardening, on-orbit autonomy, and cross-links, should provide sufficient protection for most conflict scenarios.

2.6 Military Space Systems and the Principles of War

As we can see from the foregoing, the world is a rapidly changing place - a place with continuously disruptive impact on even the best military planners' approaches to the architecture of our military forces. Without well founded underpinnings for our military force architecture, force structure and training , we often are accused of preparing for the next war by designing the last one. For this reason it is instructive to return to first principles when we examine the needs for our space architecture of the future. As the race of technology unquestionably establishes space as a future theater of war, it is important that we build an architectural foundation for space which draws on the principles of war. These principles have been stable over the ages, changing only in their implementation through technology rather than their fundamental thrust and provide general guidance for the conduct of war at the strategic, operational, and tactical levels.

As space capabilities are applied to terrestrial systems, they so change the terrestrial force capabilities that the application of the principles of war begin to change fundamentally. This in turn is reflected in the command, control, and employment of the forces, and even in the form of warfare that may be employed, and the very objective of the conflict may change as new means become available to influence the enemy decision maker.

Independent of what changes occur, just as with the concept of freedom of navigation on the seas, we must guarantee the right of free passage of U.S. and friendly flag carriers in and through space as well as deny that ability to space systems who threatens our national security interests in time of war. We must guarantee that free right of passage because space systems can

make valuable contributions to our civil, commercial, and land, naval, air and space war-fighting forces, whether in day-to-day, peace time operations or as we employ whatever force is required to meet our national security objectives.

For years the military has considered space in the context of mission areas such as communications, navigation, or tasks such as space control and force enhancement. Much of the way we currently view space systems is channeled by these convenient, but often over-simplified definitional areas. Modern day thought about satellites stands where our thinking about the airplane stood at the early stages of World War I - as scouts or messengers. Most contemporary thought about the contribution of space systems to the military has started from today's requirements , and most of it, while making valuable contributions, has concentrated only on pointing out current shortfalls and describing how to make only incremental advances to today's state of the art. Those advances have been aimed at satisfying near-term requirements.

Looking ahead we should consider three types of contributions that space systems can make to future warfare: (1) as support to all terrestrial warfighting, (2) as support to individual land, naval and air components, and (3) as a separate, unique warfighting arena. In terms of Principles of War the impact that space systems can have on future warfighting can be described as follows:

Objective. - directs every operation toward a clearly defined, decisive, and attainable objective. Space provides the means for precise coordination of beyond-the-horizon land, sea, air and space operations and will contribute to the outcome of conflicts either as weapons or as critical parts of the military decision cycle. They will assist in the direction of fire and targeting of weapons, especially as space systems become critical parts of weapon loops. Increasingly, space control broadly defined as both physical control and information control will be a prerequisite for effective land, sea and air control.

Defense. - resists attack through appropriate operations, positions, or attitudes. Detection satellites will provide warning to terrestrial forces, giving the time needed to defend against attack and gain offensive initiatives. Information gathering provides indications of enemy actions and intentions and optimizes defensive positions. The proliferation and omnipresence of space assets will make defense of terrestrial assets much more difficult. The attack potential from space will stimulate the development of defensive weapons and countermeasures such as lasers, directed energy, and kinetic energy weapons.

Offense. - is a decisive way to seize, retain, and exploit the initiative, and with it, gain freedom of action to pursue the objective. Space operations provide the capability to project power globally, and disrupt, or even completely unhinge, an enemy's strategy by forcing the foe to react, rather than act, and conducting the conflict in a time and place of our choosing. Proliferated satellites will provide timely information to globally dispersed users, assisting coordinated offensive operations among multiple forces. Long range terrestrial offensive weapons supported by space systems will increasingly threaten all fixed and moving targets. Offensive operations against satellites will first include physical attacks from the ground and inevitably later from space. Farther in the future weapons in space are inevitable. The ability to strike with space-based weapons can produce substantial global threats. Such a capability will provide a strong incentive for the development of precisely targeted weapons from space to ground or space to space.

Surprise. - is to strike at a time, place, and manner for which the enemy is neither prepared, nor expecting an attack. The high dependence of the military on satellites will make space a good candidate for initiation of hostilities. Surprise strikes will result from satellite collection, and synchronization of those strikes involving separate force components will be aided by satellites. Strikes conducted directly from space will give a new surprise dimension to warfare. Satellites can also provide early warning of attack to reduce surprise.

Mass and Concentration. - focus of combat power at the decisive point in time and space. Rapid deployment and dispersal of forces will be aided by space systems, both to support normal operations for forces on the attack and to avoid attack. Using space systems precision target interdiction effectiveness will be considerably improved. Positioning satellites will provide a uniform position and time grid permitting massing, rendezvousing and refueling, close-in surgical strikes, and concentration of forces to take place with increased precision.

Concealment and Deception. - is to hide forces from observation; cover, mask, and disguise them; mislead, delude, beguile, and divert the enemy by all possible means. Specially designed systems can be used to assist in the detection and identification of camouflaged and concealed forces. Locations of military forces can be denied to space systems only by effective deception. Because of the multiplicity of space systems, deception against detection must be effective against many space systems, and the high probability against simultaneous deception of all space systems will be a major driver for the need of antisatellite weapons. Collection and dissemination of false data will deceive an enemy, while properly executed deceptions will draw an enemy to vulnerable locations. Effective use of maneuver and system design techniques will contribute to surprise, deception, and survivability.

Economy of force. - calls for allocating minimum essential combat power. Space systems increase the effectiveness of terrestrial combat. Satellites will optimize target sets for strikes by a spectrum of weapons systems, and will reduce the need for organic assets. Space systems will allow a better determination of optimum attack/defense force ratios. In general the transfer of good information between ground and space-based assets will optimize the use of all weapons systems, assuring economy of action.

Maneuver, timing, speed and tempo. - place the enemy in a position of disadvantage through the flexible application of combat power. The keys to effective use of satellites in wartime are rapid tasking, data collection and fast delivery of targeting information to the shooter. Such a process will operate in an environment of near real-time, near-continuous coverage of force movements by space systems. More accurate position determination from satellites, combined with accurate timing of maneuvers, will lead to better coordination of strikes and maneuvers, tighter operational timing, higher speed maneuvers, and more effective use of smart munitions. Better satellite-derived positions will permit forces to fight battles at more advantageous time and places, and allow the strategic direction to be rapidly changed, unhinging the enemy defense.

Deployment. - is to rearrange forces for the attack, or spread them out to minimize the effects of enemy attack. Space navigation systems will provide very precise timing and position information for force deployments and the optimum, timely execution of those deployments will be improved. Vectoring of forces onto strategic and tactical targets will be more effective through the use of precise navigation information. The global communications provided by satellites will optimize deployment of forces; space will continue to be a major player in strategic

deployment. A rapid on-orbit replenishment, replacement, or deployment capability for satellites will be required under most wartime military scenarios. Satellite deployment will consist of launched on schedule , surge on demand, or the activation of satellites stored on orbit.

Battlefield Friction, the Fog of War. - Varying levels of confusion exist during combat engagements. Denial of satellite-derived information will tend to blind operating terrestrial forces, reducing their effectiveness and slowing them down, and the disruption of satellite communications will be a major contributor to battlefield confusion. Since most satellites are unmanned, identification of the source of a "soft" attack on a satellite is difficult. Disruption of relay satellites will be a force multiplier in the fog of war, for many links to decision makers will take place simultaneously for many operating satellites through relay satellites.

2.7 Future Space Applications

As we apply space power to the principles and practices of war, it is critical to exploit space to attain and maintain information dominance of the future battlespace. As this revolution in military affairs is occurring - the major driver will be space systems support to the warfighter, producing a significant force multiplier effect. Space systems provide the capability of maintaining tempo of combat operations day/night and all-weather. The product is an integrated and synchronized terrestrial force such that decisive combat power can be applied at the desired time and place, thereby rapidly overwhelming the enemy with minimal friendly losses. This means we need a paradigm shift from the old way of thinking about space to new ways. We need a "system of system" approach, rather than the "stove pipe" approach of the past, The focus on future dedicated military systems has to include civil and commercial, national and international elements and technologies.

A major force propelling and shaping this paradigm shift is the importance of information. Information for most conflicts has become the center of gravity, and the capability to wage information warfare becomes essential to win. Information warfare may be more effective in collapsing the enemy than traditional military force. Furthermore, as information becomes increasingly pervasive, concepts for information based warfare will be developed, further changing the nature of warfare and force size, structure, and capabilities requirements.

The space systems role in information-based warfare has become central to military operations. Space is crucial for the "information" in information-based warfare, so that U. S. forces can respond to changing operating environments and advanced threats. A huge mass of data will be available from collection systems, and many different users, and this data needs to be processed into information to be useful to the warfighter. He needs just the right information at just the right time—day/night and all-weather. This means information fusion for true global presence. To create and distribute knowledge as a commodity, reliance will shift from large expensive national systems to integrated architectures of distributed systems and smaller tailored satellites deployed to support warfighters. Total awareness of the environment will become a necessity for global presence and with it the knowledge of who and where is the enemy and where are the friendly forces. The end goal will be the omnipresent view of the battle field in real time in all weather. It will require continuous world wide coverage of any location at militarily useful resolution in addition to exquisite information levels of special areas for technical intelligence.

Dominance of information based warfare requires control of space. Space control will be exercised at all levels of escalation by detection, denial, degradation, disruption and destruction. Passive and active protection measures will be taken for friendly space assets. Space warfare will expand to include not only LEO/MEO/GEO assets, but also military operations may well extend to the moon and Lagrangian Points, as well as deep space.

Eventually for the U. S. to exercise its superpower status it will be necessary not only to show global awareness and presence through space based information which would aid in lethal precision strike with submeter accuracy, but also to be able to project power from space directly to the earth's surface or airborne targets with kinetic or directed energy weapons.

Just as terrestrial geography is important to terrestrial operations, the geography of space and space weather will become important to space operations. Space debris will be controlled through international discipline and agreements, active avoidance measures and clean up. This will require synoptic monitoring of space debris.

A number of new or enhanced technologies will emerge, to include the following:

- Technology for multi-spectral and hyper-spectral imagery, distributed optical phased array apertures and efficient transmit/receive modules to facilitate comprehensive surveillance platforms using all appropriate bands of the electromagnetic spectrum
- Real-time, all source intelligence fusion in command centers and readily available by push or pull by user at all echelons
- Massive on board processing to facilitate reliable automatic target recognition and target damage assessment
- Space based submarine detection and real-time ship tracking
- Space relay of terrestrial data free of bandwidth limitations
- Improved, non-jamable positioning information on weapon and target location at all times providing weapon delivery with centimeter accuracy
- Routine global, real-time equipment/logistics monitoring and reporting system
- Information on demand will be available to the local commander anywhere on the globe anytime. Local theater exclusions and enhancements will be developed to fight wars without disrupting global commercial operations.
- Power beaming to transmit energy to space and energy from space to ground will become a major element of space operations. We will learn to use tethers in space for survivability and exchange of power for energy to affect space maneuvers.
- Completely internetted information systems will change the way our armed forces fight. Human machine interfaces will be anthropomorphic leading to eventual human/satellite fusion. Humans will be able to manage at higher levels and let the machines assign and do specific tasks.
- The deployment of a robust space transportation system composed of reusable and expendable launch vehicles which will make access to space affordable and

provide services at cost competitive to airborne/ground systems with better global presence and timeliness will be completed. The space launch capabilities will include launch on need, transatmospheric vehicles, and a capability to place payloads in moon, and deep space orbits.

While the decades-long debate on the utility of military human in space still continues, it has been clear that space systems are manned by military personnel on earth. Looking to the future, military operations may well require that military personnel operate in space if the value of trained observers operating in conjunction with other equipment proves to be significant. The application of human capabilities applicable to on-orbit operations has been tempered by the constraints on men operating in a hostile space environment and the associated high costs. We need to gain better understanding of the man/machine trades relating to space support such as maintenance/assembly activities or an R&D laboratory to develop optimum designs of space systems and to determine the optimum mix of manned and remotely-controlled space systems for cost-effective space operations.

Complicating such a program is the difficulty in developing a dedicated military system. A manned military laboratory could be part of the International Space Station, but there are obvious drawbacks in establishing and operating a military laboratory in an international environment. If other countries have modules dedicated to national activities, such drawbacks may be mitigated.

A Summary Vision: Information-based warfare is creating a paradigm shift for space forces. They must be global, routine, timely, reliable, trusted, user friendly, just enough, survivable, affordable, and with a goal of creating a unified battlefield. These capabilities, which evolve from the "system of systems," resulting from space application "push" will cause fundamental modifications in the employment of terrestrial systems that implement the principles of war.

3.0 Warfighter Space Mission Needs

3.1 Joint Mission Requirements

Future warfighting will be joint and space will be crucial to a successful conclusion. The effective use of space requires a space-knowledgeable cadre of dedicated and motivated military officers and civilians. The joint warfighter's space requirements for the exploitation of information available only from space spans the warfare spectrum from indications and warning to weapons on target. Future conflicts must be fought by a holistic force to leverage the synergism between integrated land, seas, air and space elements and depends on the type capabilities in which we now invest. Any information that is not readily available to the warfighter, the one with the ultimate responsibility, is irrelevant. The battlefields of the future, across the entire range of situations whereby military forces might be committed, will be ever increasingly dynamic, faster paced and of greater dimensions. There will be a requirement for continuous global, three dimensional positional situation awareness, under day/night and all weather conditions, with less than one meter accuracy and temporal data tethered to GPS time standard.

Space should act as the medium from which to acquire the information that can only be achieved from space or can be obtained more economically from space. Space provides broader area coverage than any other means for a plethora of sensors to support a wide range of missions. However, there is a pressing need to relax the classification of information harvested from space to better enable the satisfaction of a greater number of extant warfighter requirements and provided real-time support for mission planning and operations. Space systems of the future must be a part of a "system of systems" that can not only provide the joint warfighters, but coalition forces, with all of the information necessary for "information dominance" of a unified battlefield. This "system to system" architecture should be an integration of a wide array of space capabilities that includes, among other things; SAR imagery, multi-spectral imagery, GPS, and/or its successor, meteorological and oceanography information, ELINT, satellite communications, and the other potential space capabilities that awaits exploitation. There is a need for a "system of systems" space doctrine that contains existing and planned space capabilities that can be critically analyzed during joint exercises and through modeling and simulation to improve its architecture and effectiveness.

3.2 Ground Based Force Tasks

Space has become an integral component of the Army's technological and operational evolution. The Army is a leader in the use of space products and in the tactical applications of space systems. Today, the Army may be the largest user of space systems on the battlefield. Integration continues in all functional areas of space with modest investment in communications, positioning and navigation, intelligence , weather and environmental monitoring, terrain analysis target acquisition and missile warning. The Army is already critically dependent on the positioning and navigation assets in space with validated future requirements for 95,000 positioning and locating receivers, many embedded into aviation assets both current and planned During Operation Just Cause, tactical applications of space assets included the use by many widely dispersed small units of single-channel tactical satellites as the only reliable means of secure communications available. Commercial satellites were used to transmit still images and the Army's CONUS-based tactical intelligence production section transmitted intelligence overlays

directly to Panama, portraying targets for use in the commander's intelligence preparation of the Battlefield. During Operation Desert Storm, the Land Component Commander was dependent primarily on satellite communication to control the rapid movement of very large and widely dispersed armored formations. Defense against tactical ballistic missiles became an operational reality for land component commanders in 1990 before and during Desert Storm. That defense was thoroughly reliant on space based sensors and communications, both DoD owned and commercial, to operate. In Haiti, space products provided deployed forces with critical communications connectivity, timely intelligence reports and high resolution maps. Today, the Army's intelligence functional area is completely dependent on spaced based sensors and communications to gather, fuse, and disseminate the intelligence products necessary to command and control all ground operations.

In the future, space assets, capabilities, and products will critically affect the conduct of land military operations across the entire spectrum of those operations. Access to national, civil, allied, military and commercial space capabilities and products will be essential to successful land operations.

Employment of space products that meet land warfighter requirements will provide a force multiplier essential to a power projection land force, which will always operate jointly and more often combined with allied forces.

The use of space products and application of those products will be embedded in land force doctrine, training, simulations, wargames and plans, and will be part of all preparations for and conduct of assigned missions of land component commanders and warfighters.

This section provides a summary of the land warfare missions and tasks which create a demand for space products and places those products within a framework of performance requirements which will help define system design, ubiquity, survivability, reliability and robustness. This information in turn, provides Air Force planners the information to frame the future design, procurement and operations of space based systems and products to support the conduct of land operations.

The application of space products in the Army and Marine Corps, the forces which conduct operations on land, is in the main, a joint activity. This means that while the Air Force is the principal designer, deployer and operator of systems which reside in space or responsible for acquiring space products from a variety of non- DoD sources, the land components are the principle designers, deployers and operators of the systems which receive and use the products of space based systems. Therefore, the characteristics, products and operational modes of space systems must be developed in consonance with the ground systems which are designed to support the requirements of landforce warfighters. Space based products will normally be part of a large web of other products and resources from non spaced based systems which have been combined or used concurrently to create capabilities which satisfy the demands created by ground operation missions and tasks. In many cases, space based products will provide unique capability to support ground operations, but they will be used in a system of systems environment.

Space based capabilities in support of ground operations can be grouped generally into the following categories :

- Communications

- Provides reliable transmission of command and control information between and among formations conducting ground operations
- Provides long haul communications links for intra and inter theater combat and support activities
- Moves sensor data from spaced based and non spaced based sensors to support intelligence and targeting processing system

- Position, Navigation, and Digital Mapping
  - Provides three dimensional position, location, and navigation
  - Assists synchronized operations through precision timing and locating
  - Provides information to determine precise enemy location and target acquisition
  - Provides the digital terrain data to support the digital transmission and integration of topographic and feature data to one meter resolution for anywhere in the world
- Reconnaissance, Surveillance, and Target Acquisition
  - Provides global and local observation of both friendly and enemy activity and facilities
- Weather, Terrain, and Environmental Monitoring
  - Permits advanced knowledge of the environment and its effects on friendly and enemy soldiers, formations, and systems to support mission planning, situation awareness, and synchronized battle management
- Missile Defense
  - Provides early warning of missile attack
  - Cues tactical missile defense systems to missile attack
  - Targets enemy launch systems
  - Provides counter-proliferation surveillance

Warfighting Missions and Tasks. The U.S. Army will continue to be a power projection force which will be required to conduct decisive combat operations in support of regional contingencies anywhere around the globe from a continental base. It similarly must be able to conduct operations other than war around the globe with minimal warning and preparation time. The Marine Corps will continue to be primarily a forward deployed force afloat which can be employed quickly to conduct combat operations in regional contingencies distant from the continental base of support. Both forces must be prepared to conduct forced entry operations against a wide spectrum of forces from the best equipped and trained to those at minimal levels of capability. The requirements placed on space based capabilities for both forces should be designed to support the most demanding circumstances.

Project the Force Capability. Because the majority of Army forces will be located in the continental United States and a large support base will remain in CONUS, split based operations will be normal whenever a portion of that force is deployed. While in preparation for deployment and enroute, the force will require information to conduct intelligence preparation of the battle area of operations and begin rehearsals for mission execution. Global communication pathways will be immediately required to support the functional areas of movement, intelligence, command and control, force protection, .and logistical support. Joint and multinational connectivity will be necessary from the beginning of any force projection operation.

Force projection will require functional space based capabilities to:

- Provide en-route communication which have assured access, global coverage, large band width capacity, interoperability with other service and allied communications, and flexibility
- Disseminate intelligence to forces enroute by sea and air
- Provide terrain and weather data on the deployed area of operations and en-route
- Produce digital mapping information to construct maps, update systems embedded mapping data, and support mission rehearsals
- Provide capability to maintain total asset visibility

Protect the Force Capability. When a force deploys, it becomes vulnerable to a wide range of threats which can prevent or diminish the capacity of its individual members to operate effectively, its systems to function with high efficiency, and its organizations to maintain the ability to move, shoot, support and communicate. Deployed operating forces must protect themselves against hostile weapons such as tactical ballistic missiles, chemical and biological weapons, and the possibility of larger or more capable enemy formations especially during periods of forced entry operations and force build up. The need to minimize casualties and to return sick or wounded quickly to fighting capability will be more important in future land combat because of the continuing rise in battlefield lethality and the likelihood that the US ground forces will operate with reduced physical presence. In an information rich battlefield environment, situational awareness will be an increasingly important aspect of force protection because it enables the force to engage the enemy forces at greater depths.

Force protection will require functional space based capabilities to:

- Enable real-time weapons detection and launch notification
- Determine and report in real time launch point identification
- Determine and report impact point identification in real-time with direct broadcast force wide
- Maintain wide area multispectral sensor coverage to deliver data for the development of total situational awareness
- Provide the means to execute telemedicine operations from CONUS to theater
- Provide detection capability for chemical, biological agents and enable global broadcast warning messages

- Provide ability to distinguish friend from foe through combat identification capability

Control the Force Capability. The battlefield of 2010 will experience a revolution in the ability of ground commanders to command and control the forces conducting operations. The capability to collect, assess, and move information better than an opponent will be the principal determinant for successful, decisive ground operations. The competitive advantage will derive from the quantity, quality, and usability of the information. Tomorrow's ground forces must be able to observe the battlefield in real time, orient the force continuously, decide continuously, and act continuously. US ground forces must be able to execute, mount, and recover from operations ranging from war to peace keeping operations, orchestrate all of the battlefield operating systems faster than the opposing forces. US ground commanders must be able to control the environment, day and night, in all weather conditions, and deny the enemy the ability to control or use the environment to his advantage. .Commanders must be able to control the tempo of operations through all phases from early entry to decisive operations. They must be able to place the right force at the right place at the right time. Commanders must also be able to control the battlespace within which they are operating. They must have the capability to move faster then the enemy, overmatch the enemy's combat power at decisive points, and be able to operate inside the enemy's decision cycle. Force control requires real-time intelligence, total situational awareness and the knowledge to navigate anywhere, at any time.

Force Control will require functional space based capability to:

- Provide combat identification of friendly equipment
- Provide wide band communications for intra-theater dissemination of digital data to build common picture of the battlefield, real-time Intelligence development, and shared situational awareness
- Provide capability for satellite based position and navigation information for embedded navigational systems on vehicles, aircraft, and for individual soldiers
- Provide real time terrain and feature digital mapping data and disseminate on wide area direct broadcast for inter-theater intelligence support systems
- Sensors which develop real time battle damage assessment information about enemy forces

Maneuver the Force Capability. The ground component of a joint or combined force seeks to create decisive impact on the conduct of a campaign or major operation. This is done by either securing operational advantages of position before battle is joined or exploiting tactical success to achieve operational or strategic results. To create decision, operational formations must regroup, deploy, shift, or move within the theater of operations from less threatened or less promising area to more decisive positions elsewhere. Movement and maneuver can be by sea, land ,or air. Maneuver includes the functions for enhancing the mobility of friendly forces, degrading the mobility of enemy forces, and controlling a land, sea, or aerospace area. Maneuver and associated movement are defined in terms of time of occurrence, space of activity, and by speed of formations and the weapons and logistical support system associated with them. Central to all successful maneuver is a common view of the battlefield by all of the forces included in and supporting the operation. Shared situational awareness coupled with real-time forces

synchronization enables simultaneous application of combat power across the entire battlespace, by strategic, operational, and tactical assets. Total knowledge of enemy forces and capabilities, the environment, and joint and allied forces is required to control the tempo of maneuver and dominate the battlespace.

Force Maneuver will require functional space based capability to:

- Provide real-time weather data to ground force planners and commanders in wide area broadcast
- Position sensors to locate both moving and stationary targets from individual weapon size to large formations and maintain continuous observation of high value targets. Direct downlink of target data to individual shooters will be required
- Provide terrain and feature coverage to develop and update terrain digital data bases
- Provide capability for on the move communications from individual soldier to the largest ground formations

3.3 Sea Based Force Tasks

In support of our country's National Security and National Military Strategies, Navy's focus is on its inherent ability to conduct forward operations for peace time presence, crisis response, and regional conflict intervention, while maintaining a credible strategic deterrent. Navy has historically been a huge user of information from space and communications satellites to distribute this information to globally deployed ships and its future space requirements will multiply manifold. Over 70 percent of the Earth's surface is Navy's potential operating area. Navy has unique space needs, in areas where others do not, resulting in a lack of constituency for which to compete for requirements priorities, e.g. open ocean surveillance, charting and mapping of coast lines between low and high tides, bathymetry, etc. Understandably, commercial communications satellites, particularly the over crowded Ku and C bands, are focused over land and primarily high density, populated areas, limiting these communications satellites utility to Navy.

Sea based space requirements are linked to Navy's "From the Sea" strategy, which calls for naval expeditionary forces to operate in forward areas, and will be used to accomplish its warfighting objectives in a joint environment. Navy's operating environment includes all mediums, i.e. air, ground, sea, subsurface and space and depends on space for command, control, communications, surveillance, mine countermeasures, evacuation of civilians, search and rescue, battlespace dominance, power projection and force sustainment. Submarine communications requirements are especially unique and challenging as they must be low probability of intercept and low probability of detection and submarines frequently must operate in the polar regions where there is limited satellite communications coverage. These environments will not change, nor will Navy missions significantly change for the next 20 years, but there will be major increases in the support required from space. That space support must enable Navy to carry out its missions with shorter timelines and greater accuracy and lethality.

Navy in Space. Navy has been a leader in exploiting space since 1960 and will continue to pursue every potential benefit from space. It will continuously identify long range naval

requirements, system concepts and technologies. Because of Navy's high mobility, naval space systems must be flexible, adaptable, scaleable, easily reconfigureable and be totally interoperable with a wide range of systems. Navy's warfighting necessities include imagery, rapid targeting, intelligence data base transfers, multiple netted voice circuits, myriad telephone circuits and video teleconferencing. Navy will enter the next millennium using its current suite of communications satellites, continue to field its UHF satellite follow-on program, with the latter satellites having an EHF capability and buy within the next two years all of its remaining EHF terminal requirements. The Situational Awareness Beacon with Reply (SABER) system, a satellite communications based beacon assembly, will mature and be expanded to become a global system that will provide highly accurate three dimensional situational awareness and prevent fratricide. Navy will continue developing its Lower and Upper Tier Ballistic Missile Defense systems.

Navy space policy is delineated in Secretary of the Navy Instruction 5400.39B of 26 August 1993. Space capabilities are to be fully integrated into Navy's innate and emerging capabilities and integrated into every facet of naval operations. Navy recognizes that its forces are heavily dependent on support from space and its primary focus is to provide space-based support to the warfighter. Navy depends on space derived information to perform these missions: surveillance, strike, battle group operations, operations other than war, logistics and maintenance, and special, air, submarine, surface, amphibious, and information warfare. Navy will continue to develop, acquire, and support the operation of, either alone or jointly, space systems which will satisfy its unique requirements.

Surveillance and warning. Navy's surveillance and warning requirements covers all of the ocean and littoral areas of the world and include the detection, tracking, and targeting of non-cooperative air and ground targets (aircraft, cruise and theater ballistic missiles, mobile launchers, etc.) in near real time. For theater missile defense a direct down link for IR data to warn and cue missile defense systems, a capability to assess raid count and maintain individual target tracks throughout missile's flight and the ability to determine with great accuracy the missile launch point is needed. There is a requirement for the ability to detect and locate underground, hardened targets such as nuclear, chemical and biological production facilities, as well as command and control centers. With the end of the cold war, Navy's indications and warning and surveillance focus has shifted from combating the Soviet Ocean Surveillance System (SOSS) to the threats posed by a large variety of littoral countries' threats, with the attendant diminishing response times. Navy uses space, aircraft and/or shipboard surveillance and warning sensors to gather information and provides that information to the shooter through either space or aircraft systems. Navy will continue to integrate space derived surveillance and warning information with information acquired from organic shipboard and aircraft systems and any other joint information sources.

Reconnaissance. Navy has a continuous , near-real time sensor and satellite coverage requirement for its areas of responsibility. Information from carefully tailored and profiled information domains needs to be provided via downlinks directly to operational commanders to support tactical threat warning, strike planning, BDA, and re-strike planning. Automatic target recognition techniques and algorithm development are needed to more quickly recognize the presence of targets. Improved sensor performance is needed to enhance the precision in geolocation of conventional radars, including the intercept and locating of unintentional modulation of non-military shipping. One of Navy's unique space reconnaissance requirements

is the location of mines. Multi-spectra imagery obtained commercially has proven to be helpful in locating mines in shallow water, but a SAR and/or LIDAR capability is required to detect sub-surface sea mines.

Communications. Navy communications are inextricably dependent on satellite communications for its every mission from peacetime forward presence to war at sea. SATCOM is the lifeblood of and the essential link to naval forces. The salient features required for naval SATCOM are high bandwidth, assured access, global coverage, interoperability, security, and an architecture that is flexible and easily reconfigured. Navy has and will continue to depend on satellite communications spanning the entire frequency spectrum, i.e. UHF, L-band (commercial INMARSAT), SHF, and EHF, and in the future higher frequencies, i.e. millimeter, infrared and optical wavelength. It uses both military and commercial (INMARSAT, INTELSAT, etc.) satellites, including commercial satellites that drift due to fuel starvation. In the UHF spectrum, Navy utilizes FLTSAT, LEASAT, GAPFILLER, and UHF FOLLOW-ON (UFO) satellites. In the SHF spectrum, it uses DSCS, NATO and SKYNET satellites and at EHF, Navy employs the FLTSAT EHF PACKAGE (FEP), UFO-E and MILSTAR satellites. To better exploit its communication network, Navy needs to develop an automatic and dynamic network control and management system that will adapt to demand, be media independent and invisible to the user. Because of a paucity of real-estate on ships, antenna sizes are limited, aggravating the power/aperture problem and restricting bandwidth. Navy' primary communications technological requirement is for a phased array high gain antenna that is electronically steerable and capable of accessing multiple satellites, operating in any frequency band, in different parts of the sky simultaneously. It must rid itself of the antenna forest aboard ships i.e. 120 antennas on a Nimitz class carrier. Navy's bandwidth requirements at sea will far outpace emerging technologies ability to satisfy. A conservative estimate is that 20 gbps will be required for flagships by the year 2015. Navy at sea commanders must have access to large reservoirs of information that contain information about friendly and enemy weapons systems, platform capabilities, enemy order of battle, satellite ephemerides, enemy signals, etc.

Navigation and Positioning. Precise navigation is essential for safe passage, exact positional information is the first factor in the calculus for any targeting solution and accurate geolocation is crucial for Navy's precision guided munitions. Every navy ship and aircraft should have GPS time and position information embedded in its navigation system and, if economically practical, in its weapons systems. In those weapons platforms, whereby it is cost prohibitive to integrate GPS into the mission computer, GPS should be used as the standard to enable their inertia systems to remain within extraordinarily accurate position tolerance.

Weather. Navy has myriad requirements for accurate and continuos weather information spanning the spectrum from evading storms and heavy seas to avoid ship damage, to making weapon systems more effective, to using winds and tides for economical steaming or flight operations. Navy must have accurate and timely weather information to achieve a strategic and tactical advantage. Weather is a major, if not a determining factor, in every dimension of naval warfare. The commander at sea requires information on sea surface topography, sea state, sea ice edge, ice thickness, bathymetry, sea surface temperature, sea surface wind vectors and velocity, sound velocity profile, and cloud opacity, bottom height, thickness and particle size and be able to observe, measure and record temperature, humidity and atmospheric pressure.

3.4 Airborne Force Tasks

Air warfare is the province of no single service, each has air components which may operate independently and in support of joint surface forces. What distinguishes the forces is the medium in which they operate, the territory over which they can range, and the timeliness with which they can respond. Air components can operate across the entire spectrum of conflict and have. While general US Air Force service issues have been addressed throughout the report, the joint air warrior's needs require specific discussion.

The medium in which they operate. The special risks of operating in all weather day and night conditions have challenged air warriors since the first day of military aviation. The three dimensional fluid in which they operate requires characterization just as the ocean must be characterized for forces afloat. Space based weather and climatology have long supported air operations. This support will be required into the foreseeable future. Additional requirements in defining air mass behavior to ensure weapons delivery accuracy are already being stated. Further requirements, in timeliness, accuracy, and access will grow as air operations without benefit of forward-basing become the norm.

The territory over which they range. Air forces range over the entire globe. Their area of operation is virtually unconstrained. This drives the situation awareness requirements for future air forces to very high levels. First they must understand the terrain over which they will operate. This implies a significantly expanded earth surface and cultural features data base. Cold War imperatives and space systems limitations during the era seriously constrained the amount of data collected, processed, and distributed. Most of the world today is mapped and charted to an accuracy insufficient to support the intrinsic capabilities of future air forces. The inability if the air warrior to correlate his tactics to the terrain will reduce effectiveness and increase losses. Second, they must understand the targets against which they are operating. The cold war conditions identified above have created a lopsided repository of information which lags the warfighters' needs. Classification boundaries have kept this information from those who need it to ensure mission success and their own survival in some instances. As weapons technologies allow us to move to general "one shot, one kill" operations such as demonstrated by F-117s in the Persian Gulf, air warriors must be afforded target situation awareness of comparable accuracy. Third, the essentially unlimited range of air forces implies a new concept for communications. As we learned in the Persian Gulf, no country in the world enjoys the communications infrastructure the US does. The ability to move the information required for acceptable situation awareness is fundamental to future air warfare. This implies not only requirements for masses of data into a theater which far exceed those we experienced in Desert Storm, it implies the ability to move situation awareness information directly into the cockpit. To a lesser degree, the air crew on the scene is an important part of the air component commanders' situation awareness; information out of the cockpit takes on a new meaning.

The timeliness with which they can respond. The ability of air forces to get to the target has outstripped the ability of the forces which support them to provide the information necessary to the successful conduct of operations. This leads to conservative tactics which allow our adversaries an opportunity to consolidate their forces and provide a substantially more hostile reception for US forces. Future air forces will require support which keeps pace with the overall tempo of the operation.

All of these point to an air warriors' requirement for information which is accurate, relevant, and timely and a concomitant requirement to interfere with an adversary's information such that, in varying degrees at various times, it is none of these. Space systems are uniquely suited to meeting these requirements. They can produce information of extraordinary accuracy. They have allowed access to denied areas. They can provide a universal infrastructure. And, they can be employed to interfere with information flows. These functions can be performed globally and virtually at will.

The natural extension of air into space leads to the natural opportunity to extend air operations into space. Doing so complicates the adversary's strategic, operational, and tactical challenges, and may afford an entirely new of projecting force.

3.5 Space Based Force Tasks

Force Enhancement. As can be deduced from the preceding sections, the historical and current focus for space force tasks is in the area of providing information to land, sea, and air components to enhance their operations. This information is either collected by space-based platforms or transmitted via space-related platforms in the areas of observing and characterizing the battlespace, organizing and executing the battle or enhancing and predicting conditions within which our forces must operate. Classically these capabilities have included reconnaissance and surveillance, navigation, communications and environmental sensing. The tasks to support these areas include all activities required to operate the individual systems, process the data collected and transmit the resulting information to the end user - the warfighter in his area of responsibility.

Future efforts in the force enhancement area will focus on placing higher dependence on space to support the warfighter, possibly by further integrating space into future battle. Implementing a space-based radar capability to take over the role of AWACS is one way of increasing this space involvement. Another would be in further integrating the selected information, such as GPS, into weapons delivery platforms. The inherent qualities of space in terms of wider field of regard and instantaneous access make these efforts very responsive and potentially very cost-effective when system trade-offs are made.

Space Force Support. Space force support includes missions carried out by terrestrial elements of military space forces. The objectives of space force support are to sustain, surge, and reconstitute elements of a military system or capability. These activities improve or sustain space vehicles in space, direct missions and support other government or civil organizations. Examples include spacelift, replenishment operations and satellite operations. Spacelift encompasses all activities necessary to launch, achieve initial operating orbit and reposition satellites already in orbit. Satellite operations provides the infrastructure required to command and control the DoD satellites once they are on orbit. It is worthy to note that the military, civil and commercial launch infrastructure within the U.S. is highly integrated and we are currently examining expansion of our satellite operations customer base to include support to commercial efforts.

Space Control. It is universally accepted that the warfighter must achieve and maintain air and space superiority to win. To ensure space superiority, control of space is mandatory. As access to space capabilities proliferates through the world the impact on the battlespace will be

felt in many areas. Future commanders can reasonably expect their adversary to have space based capabilities available to them and also to appreciate the value of space to the U.S. This necessitates a much greater emphasis on space control. Space control assures the friendly use of the space environment while denying its use to the enemy. The elements of space control include surveillance of the space environment, protection of U.S./Allied space capabilities prevention of adversarial interference with U.S. space exploitation, and the ability to negate our adversary's access to space.

Space surveillance capabilities are relatively mature. As satellite constellations proliferate, especially with proposals such as Teledesic, and the sizes of satellites decrease, the volume and complexity of the space surveillance job will increase. Means to expand our surveillance capabilities while maintaining cost effectiveness must be examined. Comprehensive space surveillance allows for overflight warning from potentially hostile satellites to units in the field, accurate assessments of payloads and targeting and Battle Damage Assessment in support of protecting U.S. assets or negating an adversary's.

Survivability of U.S./Allied space systems will be increasingly important as capabilities to disrupt and deny space data become common. Unintentional interference with space systems is commonplace, intentional interference only requires a focused intent and rudimentary capabilities. Additionally, vulnerabilities of our ground nodes to information warfare techniques must be examined in detail.

Negation of adversary space capabilities has long been frowned upon as 'weaponizing space'. However, potential methods to disrupt, deny, degrade or destroy an adversary's space capabilities could take many forms. Any segment of the space system (ground station, satellite, links or data distribution) could be targeted and many means could be employed to deny an adversary access to the space data. Denial methods span the spectrum from diplomacy to destruction.

4.0 Space Missions and Their Applications to Warfighting

4.1 Reconnaissance and Battlefield Awareness

Julian Caballero, Jr., Keith Hazard

4.1.1 Summary

This paper presents ideas and recommendations designed to stimulate thought, action, and decisions about the role of the United States Air Force (Air Force) into the next century. Its focus is Global Reconnaissance, particularly imagery and its use to support military operations. It assumes the Air Force will be aggressive in working out an appropriate role in the US hegemony of the "high ground" of space not only for combat, but also for crisis surveillance of potential battlefields. Technology adequacy is the theme, but the limiting factor to technological superiority is not the challenge of advanced technologies' availability; it is, rather, the adoption of Air Force-sponsored technologies into systems meeting operational needs, simultaneously taking full advantage of commercial technology and systems, integrating these advances into an increasingly complex "system of systems," all of this in a much improved acquisition climate and process which takes account of multiple user needs, foreign countermeasures, stringent budgets, and global use of space for commercial and military-supportive ends.

At every instance where military threats challenge the interests of the United States, the Air Force must be in a position to respond directly and promptly. The Air Force, as the designated DoD lead for space, must be ready to support all United States military and intelligence assets as our national macrostate moves from peace, through crisis, to conflict. The "battlefield awareness" enjoyed by US commanders in Desert Shield/Storm led directly to "battlefield dominance," and to a quick and relatively bloodless victory. An oft-repeated lesson of history was demonstrated in the Persian Gulf: all other things being equal, the adversary with the best intelligence wins.

The role of the Air Force in this new world is as the national crisis-through-conflict "information leader." A key change in Air Force, Pentagon and congressional perception of the Air Force mission is the necessity to broaden the term "close air support" to include "battlefield reconnaissance data." The Air Force must step up to the challenge that simple statement implies, accepting its current responsibility and broadening it as described, including successful negotiation with the national agencies and the other military services to cede some of their current power and budget. Difficult as such a challenge may seem, there is actually broad sympathy for such focused leadership. We believe it is critical to the national interest for the Air Force to accept this mantle.

Technology leadership must be a byword for the Air Force, continuing from its present strong foundation, but broadening to include stronger liaison and technology transfer roles with the National Reconnaissance Office (NRO) and the users, represented by the CINCs -- ranging from the forward-area deployed soft-copy analysis station to the National Photographic Interpretation Center (NPIC), Defense Mapping Agency (DMA), and all DoD and service-related users. The Air Force should adopt a charter and vision which at least incorporates the following:

- A system-of-systems to collect, analyze, archive and disseminate information of importance to the warfighter. This should include at least weather, maps, imagery

of possible battlegrounds, condition of roads, lines of communication, weapons types, precise location during combat, and numbers, readiness and organization structure of the probable adversary.

- An array of collectors, including at least manned aircraft, remotely piloted vehicles with loiter capability (including low observable technology to permit deep penetration and long endurance on target), with all-weather sensing (through a combination of SAR electro-optical and multispectral sensors) capability, and either a permanent high orbit long-dwell capability, a constellation of single-function small satellites, or a launch-on -demand tactical satellite system with all-weather imaging capability to supplement and enhance the coverage of upgrades to current systems. The constellation of space imaging assets should reflect the different applicability of waveband to reconnaissance requirement. Specifically, 1) frequent revisit SAR of mid to low latitudes with one meter resolution should be achieved by a small constellation at low inclination, low altitude small satellites to provide all-weather, day-night observation capability, 2) baseline one meter visible, imagery should be accomplished through a judicious baseline of commercial imagery supplemented as appropriate for reasons of timeliness, revisit, and assured availability, with electro-optic small satellites and/or use at low resolution of the "high quality" low earth heavy satellites, and possibly, geosynchronous long-dwell, large-aperture systems, 3) high quality visible imagery, 4) one-meter mid-wave infrared, two-meter long-wave infrared, and two-meter multispectral from a combination of single-purpose and small satellites, and 5) ten-meter hyperspectral resolution systems for small images of analytical interest (for example, for detection of BW/CW agents or narcotics precursors).

- An open architecture to permit easy incorporation of technology advances in collectors, data storage and transmission, including all-source fusion methodologies, algorithms, techniques, and automatic and/or analyst-aided exploitation decision support systems as they become available, proven and affordable.

- An inherent ability to deploy the forward elements of the system to any part of the world on short notice and to be ready within minutes to pass desired information from all current and archival data bases to the deploying troops, systems and smart weapons.

- A strong and well-funded team to design, develop, acquire and operate the system with suitable assignment of responsibilities within the DoD, NIA, and NRO, but under the overall guidance of the Air Force.

- A policy of cooperation with commercial developers of systems and subsystems to ensure conformance with standards and availability of data throughout the development cycle and the macrostates of crisis and conflict, importantly including Air Force understanding and potential denial of commercial imaging data to enemies or their probable allies.

- A seamless interface within the government between operational users, daily operation support, and the intelligence community to ensure sharing of databases,

commonality of objectives, and straightforward cooperation during any transition from peace to crisis to conflict.

Most of these foundation recommendations are achievable with existing technologies or low-risk extensions to them. The rest are within sight—on the drawing board in many laboratories Not all are government-sponsored, hence the need, and desirability, of leveraging commercial technologies and acquisition practices, not only for the cost and speed of implementation advantages but also for improving interdependence and exploring commonality of interests.

We must "get on board" the developing infrastructure for alternatives to our large, expensive and vulnerable "best-in-the-world" systems. We should continue pursuing trades toward constellations of small satellites providing lower resolution, bur more synoptic and/or more frequent revisit coverage. To do this we must encourage and invest in advances in materials, sensors, stabilization techniques, and if necessary, light boosters (although we applaud the growing availability of commercial launch capability).

We must lead, rather than be led, in the shifting focus from watching the monolithic and dangerous Soviet Union and its successor states to watching hot spots world-wide, encouraging the development of automatic warning and alert methodologies, including the full participation and use of all-INT products, tasking, and tip-offs.

We must develop and learn to use effectively the triad of manned aircraft, UAV's/RPV's and satellites for synergistic as well as complementary intelligence.

We must recognize the advantages distributed architectures for collection, processing archiving, and dissemination—and preparation of all-source product—are virtually within reach with global systems of interconnected and intercommunication satellites just over the horizon, being provided by commercial interests, domestic , foreign, and supra-national.

We must move military user-level processing, fusion and exploitation "down the chain" from the centralized exploitation resource of a few ground stations and a few exploitation centers to the maximum dispersal consonant with advances in computer distributed storage processing and exploitation support and with the users' needs, including direct downlink to the battlefield as appropriate. There are plans to provide such data to nodes of a global grid dissemination system, but a single Do D element—we recommend the Air Force—should provide customized products based on USG-wide standards to all military users. The Air Force must commit to provide this information in the form desired by the user and in time for him to benefit from it.

A single authority for miliary space architecture development and streamlined acquisition is essential. The NRO model worked well for the immensely complex systems to date, systems targeted at "exquisite" performance against denied area targets, often for purposes of ascertaining enemy weapon design data. We do not face this complex a task for most of today's requirements. A new model with faster and simpler documentation appropriate to "less than perfect" relatively inexpensive small satellite constellations and launch-on-demand systems must be developed. Either the NRO or the Air Force is able to design, develop and produce in accordance with this new approach to provide this supplemental capability; the Air Force needs to lead in 1) setting DoD requirements sufficient to stipulate performance allocation across the spectrum of sensing alternatives, and 2) assuming responsibility for delivering the usable products on time.

Our advantage over the commercial sector and our enemies who will benefit from it, which we will retain if we keep moving, in the experience of 35 years of overhead imagery collection and analysis for intelligence purposes and our ability to systematize its use for warfighting purposes.

We cannot afford to lose this edge as other countries obtain overhead intelligence systems and begin watching us. In the final account, intelligence, even that obtained from the best satellites in the world, is only useful to the warfighter if he gets the right information first.

The technology is here, or on the way. The time to act is now. Our citizens want minimum life-at-risk defense at the least reasonable cost. The Air Force, with its charge to "hold the high ground of space," is in the driver's seat. The technologist will be an enabler of the visionary leader who recognizes both the challenges and the opportunity to meet them.

4.1.2 Introduction

This paper is prepared to stimulate discussion as well as to generate ideas about the future role of the United States Air Force in the area of Reconnaissance and Surveillance in support of Battlefield Awareness. It addresses the VISTAs time period: twenty to thirty years from now.

The business of predicting the state of technology twenty to thirty years from now is, at best risky, at worst foolhardy—crystal balls get fuzzier the further one attempts to predict. However, when carefully based on past and current state of the art, analysis and projections have proven to be useful in charting a long range strategy.

It may be argued correctly that it is difficult to exaggerate the probable advances in technology, based on the pace of developments during the last thirty years. But the real issue for planning purposes is not necessarily the rate of development, but the rate at which those developments reach maturity and are ready for widespread application.

Similarly, it is a true indictment that most technical historic long-range predictions have been notoriously in error in scope, in specificity, and in utility. We counter that:

- We have a comprehensive input from participants across the entire range of both the history and the technology of US overhead reconnaissance
- The bounds of physics, economics, and utility together focus our consideration to a realistic subset of all possibilities, and
- Extensive formal in-place R&D programs, an essential underpinning of the architecture of the US overhead reconnaissance program, have been predicting the technologies available and those needing encouragement or outright sponsorship with great success for more that 25 years

Notwithstanding our confidence, however, we are in a different, more difficult to predict, world: one which necessarily reduces our confidence beyond that we would be able to assert in a similar "Cold War World" study. During the Cold War, the pace of development and application was determined almost entirely be Government (and specially DoD) spending and only secondarily by commercial application of those developments, making it easier for our fairly narrow community to "manage" as well as predict the resulting advances. This equation began

to shift in the late eighties, and by the end of the Cold War, the critical mass had shifted to the private sector.

One needs only to look at the developments in computers to make the point. There is no reason to believe that this situation will change in the near future—there is little likelihood that Defense development spending will grow significantly. As a result, commercial development and application of technology will increasingly dominate for the foreseeable future, and, as a result, our prognostications will have to include the less well understood, quicker reaction, and broadly based (both domestic and foreign) commercial development community if we are to be as prescient for VISTAs 25 years hence as we were in 1970 for today.

Nowhere is this shift to the commercial sector more evident and more pertinent to the subject than in the satellite imaging arena. This area, shrouded in secrecy for decades, has become an actively pursued commercial space initiative, second only to communications and navigation. Once the private province of the intelligence services of the Soviet Union and of the United States, it has become a potential gold mine for commercial ventures, both here and abroad.

Much, perhaps most, of this commercial technology, both for the space and ground segments, will be either directly applicable to, or will serve as an excellent foundation for, Air Force reconnaissance technology requirements' satisfaction. All in all, we will have far greater fiscal resources and far broader interests and imagination brought to our problems but mostly not under our control, reducing the certainty of our predictions but increasing our predicted level of technological attainment at earlier times for lower programmatic cost.

4.1.3 Air Force Role in Overhead Imagery Reconnaissance

While current initiatives in the commercial sector are far less capable than the intelligence photo reconnaissance systems, buyer pressure, competition, and advances in technology will improve their capability to the point that commercial technology will be capable of challenging the performance of classified systems should the market for their products exist. This will pose a dilemma to the Defense establishment, and to the Air Force in particular, similar to that being face with the Global Positioning System: how to operate in a world in which essentially every potential adversary has access to intelligence information collected from the high ground of space—we will no longer have an operational or planning monopoly; perhaps we will no longer even be able to protect our space segments from interference or destruction, and we certainly will face communication security challenges tasking the collectors and moving the imagery from the collector through the system to the ultimate user. And, similar to the reality facing the GPS Selective Availability (S/A) neutralization by commercial innovation, in which we recommend facing reality and abandoning S/A, so too do we recognize that our foes and friends will all have useful military space imagery available to them and that we should capitalize on that same availability and reserve our investments for the margin: for those capabilities too esoteric for commercially profitable investment but still of importance to the American warrior.

We anticipate that the Air Force will retain and solidify its designated role as the DoD lead for space operations, perhaps expanding its role, in close cooperation with the National Imagery and Mapping Agency (NIMA), to include responsibility for secondary dissemination, data fusion, post-processing product preparation, customizing, final archiving, and delivery to

all DoD users. In this model, the NRO would perform R&D, development, acquisition, and operation in support of the Intelligence Community, in partnership with the Air Force which would assume an integrated responsibility with the NIMA for enabling and facilitating tasking, collection, processing, archiving, dissemination, and display of DoD imagery. The Air Force will be critically interested in, but will not be the lead organization for, the development of mechanisms for the delivery of non-current imagery collateral imagery and current intelligence supportive of current imagery exploitation.

This view anticipates the Air Force will bear the ultimate responsibility for providing processed imagery in usable form to all legitimate military users. It assumes that all agencies needing to perform studies and detailed assessments of current imagery will be provided access to the highest quality data and that those agencies may continue their manipulation and exploitation with their own techniques and resources, but it assumes that the operational user, airborne, afloat, or on the ground, will receive imagery tailored in accordance with the requirements that that user levies on the Air Force.

Implicit in this expansion of the Air Force mission must be an unprecedented level of cooperation among the user community, the Air Force overall and operations lead, the NIMA and the NRO/industry technology development community in order to achieve technologically stressing missions such as:

- High resolution imaging, correlation to maps, and data exploitation sufficient for precision weapon laydown
- Multiple sensor data fusion to enable high confidence target identification
- Intelligent machine search, interpretation, and cueing to analysts so that high confidence can be placed by the user in the efficacy of the imagery system to search large areas at high speeds without missing anything important, and in the process detecting, discriminating, identifying, and reporting all items of explicit importance, and suggesting examination of items which the smart processor believes might be of importance

This responsibility makes the Air Force responsible for providing the appropriate imagery in a timely manner to the user. As such, it includes Air Force responsibility to promote the acquisition of invulnerable space assets, significantly improved sensor capability, assured communications, and usable, useful imagery to the many classes of users serviced by this system. And it explicitly demands that the Air Force coordinate in support of the user development community to provide its products in standardized, useful formats enabling the development by the user (or other organizations) of custom exploitation equipment and software.

4.1.4 Air Force Relationship to National Agencies

National agencies have worked together to allow all "national" user agencies equal standing in the choice of technical capabilities invested in, and the timing of, new collection systems. This arrangement has enabled "beyond the state-of-art," relevant systems with remarkable technical performance within a streamlined procurement process—and it has delivered the majority of its systems on schedule and within budget.

However, the increasing complexity of communications, exploitation, custom products, and the need for rapid dissemination of imagery to be used as a real-time component of warfighting and weapons targeting requires a mew model. The technology development organization is well-equipped to implement the infrastructure to create a "system of systems" and to operate it as a commodity, but responsiveness to users remains a problem. The current system provides a product on a scheduled basis. In general the receiving agencies are responsible for the exploitation equipment; the arranging of delivery of collateral information, any machinery/software/algorithms which facilitates intelligence exploitation by fusion, overlay, registration, etc.; and for the delivery of the imager-derived-intelligence to its users. A positive example for the future is the demonstrated capability which allows forwarding imagery directly to theater. Another positive demonstration system is the development of an example "universal" soft copy exploitation system (IDEX 2). Both these demonstration technologies point to a better future, one in which Air Force (or NIMA) delivers product in conformance with users' requests; and where the military user community deals directly with the Air Force (or NIMA) for tasking, operations, and archiving. The current plan for NIMA to set standards must be closely coordinated with the Air Force. In our view, the Air Force, in accepting responsibility for delivery of its product to all users, must also lead in setting standards for archiving and delivery of imagery and imagery-derived products.

The National Photographic Interpretation Center, The Defense Intelligence Agency and other "beltway" users should be treated distinctly from the warfighters. In times of peace, these "national" users (to become NIMA, according to present plans) would generally receive the highest priority for and percentage of collection; but in times of crisis and war, the warfighting commands would take precedence. We believe the current policy should remain in force: that NPIC is an office independent of the DoD during all situations other than war; in that case, its command reverts to DoD. The wording should be changed for clarity from "war" to "state of national emergency," to allow for more orderly, and less ambiguous, transition than has been experienced from time to time. One option proposed in the NIMA Terms of Reference places NPIC and elements of DIA within NIMA, a Combat Support Agency.

Finally, the Air Force should be places in charge of the requirements process for the day to day prioritization or warfighting and military crisis collection, and the tasking committee process now in place should be recognized as equitable but needing modernization it its implementation. Secondly, NIMA should be in charge of the requirements process, both their generation and validation, which leads to the design and acquisition go-ahead for new or upgraded collection capabilities; however, the Air Force, as operational lead, should be given a prominent voice in the implementation of the decision process on how to satisfy those new sets of requirements, and the NRO, as both technologists and intelligence professionals, should have a strong voice in the trades of utility, practicality, and affordability leading to the acquisition decisions.

4.1.5 Air Force Relationship to Other Services

We approach the problem in phases or conditions, and for ease of analysis, we propose three, if only because in a grand scale they seem appropriate: relative peace; increased regional tension (crisis), and conflict (war, but we conceptually include in this macrostate any emergency in progress, for example, a hurricane, flood, or volcanic explosion.) While there are needs that thread through each of these phases, there are also needs in each which can be satisfied using

different methods, and it is this particular feature which lends itself to some possible savings. Taking them one at a time:

4.1.5.1 Relative Peace

The modifier "relative" is meant to imply a condition in which there is no active involvement of US troops anywhere in the world, although there may be, indeed, active conflict going on somewhere. The USS posture would be one of staying informed and aware of the situations around the world, and of being ready to move to a higher degree of awareness if a situation develops which may result in US involvement. Under these conditions, the US intelligence apparatus is concerned with obtaining world-wide data for several reasons:

- Keep the US leadership informed about developments around the world
- Update intelligence data books on potential conflict areas; i.e. update maps, information concerning weapon developments and acquisitions, deployments of weapons and troops, political activity and changes on both sides of the target area political spectrum; and
- Alert US forces or interests of potential danger

4.1.5.2 Increased Regional Tension (Crisis)

As the possibility of US troop involvement increases, either independently or as part of a coalition, the pace of intelligence operations will increase in the area of interest. High priority will be allocated to overhead collection of all types, particularly imaging systems. These data will be made available to the CINC responsible for the tense geographic area. At the same time, specialized and organic reconnaissance systems are prepared for activation: target data needs and missions are planned and readied, awaiting go-ahead from the political leadership. The CINC, as he develops his battle plan, will require the latest intelligence available. During this time, the types of specific data which will be essential are at least:

- Completely updated maps; current weather, specific weapons available to his foe, number deployment and level of experience of his troops, his goals, and his probable tactics
- Intelligence concerning the deployment and readiness status of probable allies to his foe
- Specific information concerning the condition of roads, railroads, other logistics, and all communications networks
- Intelligence relating to his foe's defensive capabilities regarding: antiaircraft types and deployments, possible electronic warfare systems and locations, surface-to-surface missiles types and deployments, probable targets other than his troops; and
- Intelligence relating to his foe's ability to affect or to interfere otherwise with his lines of communications and his intelligence systems.

4.1.5.3 Conflict (War or Other National Emergency)

In addition to all the sources and resources available to the CINC as he prepares for possible conflict, he and his field tactical commanders will require organic all-weather, day and night intelligence collectors. These will include at least ground and airborne systems which, working in concert with the national strategic systems, will provide the battle commanders with the necessary intelligence to have total battlefield awareness. Specifically, the CINC and his field commanders will need:

- Ready and rapid access to all national strategic intelligence available for the conflict area. This means a communications system which can access all intelligence data bases at all times, directly by the CINC
- Ability to task directly and immediately all intelligence collectors within the theater of operations; and
- Immediate on-line access to the analysis facilities in the CONUS for assistance to his forward intelligence processing centers.

What is necessary to fulfill these needs? What will give the battle commander the high ground of profound knowledge of the battlefield? What reconnaissance and data transmission technology is available today and what is available or will shortly be available in the commercial field which can help in this equation? What future technologies need to be pushed to further assist future warfighters? How well equipped will the foe be in negating our collection systems or through their own familiarity with equivalent systems, negate the utility of our systems?

Many systems and much technology is available today, and much more is in development and will be available in the VISTA timeframe. What is sorely needed is a cohesive plan -- a plan to bring the disparate elements available now into a system of systems; a composite plan to collect, analyze, store, and disseminate the intelligence required by the warfighter. Only when such a grand plan is put together and accepted by the services will they be ready to fight the next war with twenty-first century technology. It is in this area that the Air Force can best contribute; it can assume the sorely needed leadership. In fact, we insist that success in future conflict may well depend on the Air Force vigorously accepting and addressing this leadership opportunity.

A single warfighter organization, we recommend the Air Force, must accept leadership, including the management of all appropriate resources to define, train on, and use regularly in operational settings the overhead system of systems (and its communications and processing infrastructure,) including the customization and dissemination of its products across the macrostates: peace, crisis, or conflict/emergency. From the warfighter's viewpoint, peace is the time to develop and test the systems needed during conflict or emergency; the Air Force must be vitally interested in developing, through the requirements process and in active conjunction with the technology developers the systems which will satisfy the users' needs during the higher states of tension: crisis and conflict. Crisis brings with it increased intelligence flow and stressed systems capacity and prioritization conflicts. Special purpose, secondary, backup and redundant systems will be readied for deployment and must be seamlessly integrated into the overall system. Finally, war: all systems deployed and operating; defensive systems and hostile actions likely; Air Force countermeasures; and most importantly, an assured flow of continuous useful, usable imagery and imagery-derived intelligence to the warfighters.

4.1.6 Air Force Relationship to Industry/Commercial Development

Historically, the government team and industry have worked as development partners. The government generally required custom technology leaps and reduction to practice of devices of physics far beyond commercial interest or affordability. This situation led to US government funding of advanced technology for which there was little other interest; this specialized use led to the development of an elite coterie of high technology contractors well-paid to develop a small number of near-perfectly performing systems. The commercial opening of space has made unnecessary the custom development of most of the units necessary for a space-based collection system, particularly the communications infrastructure and the launch vehicle systems, because of a world-wide market and the somewhat decreased security sensitivity of US overhead system elements. On the other hand, the world-wide interest in these subsystems has both diminished the US lead and increased the risk to US systems. Further, enemy activity may include their own imagery overhead systems, sometimes provided by US contractors, or might include attempts to deny us imaging products either through satellite negation or communication disruption.

This world of semi-equals poses several dilemmas. In the past, an enemy observer has been neutralized by very direct and active means: simply destroy or nullify his reconnaissance systems. The problem, however, may be that these collectors may not be the property of the enemy, but in fact may be owned by US corporations or our (at least temporary) allies. Also they almost certainly will not be marketed as intelligence collectors, but will indeed be meant principally for peaceful purposes. Those peaceful purposes will likely continue during regional conflict periods, and simply "taking them out," by any means, may not be a practical alternative. Different, more creative alternatives need to be found. Meanwhile, we will need to make significant investments to provide us assured collection and communication.

This "one world village" brought to us by multi-national consumption and standardization is a dilemma calling for carefully established guidelines for all cooperating players. We applaud the careful analysis recently made of the "best interests of the United States" with respect to commercial imagery systems' sales to foreign countries. We expect that this is only the beginning of the trail, the tip of the iceberg, leading to a VISTAs world in which the government, with industry as a partner for development, will find industry as an antagonist through all levels of peace and crisis, but that in the end, US-supplied systems will retain some Air Force-cooperative mechanisms or control aspects which make those US products play on our side, or at least not against us, in a conflict. This approach, tried successfully in the civil imaging licenses granted to date, will be more difficult to elicit/coerce as the threat to our interests becomes lower, apparently more remote, and less dramatic than that of the Cold War, but we believe such cooperation must be achieved. And the effort needed to achieve it must be invested, each year, every year.

4.1.7 Air Force as Information Provider

The US-led coalition had the only eyes in the Gulf War. That fact was not lost on others, combatants and spectators alike, and every country or group of rebels in the world with less than peaceful goals toward their neighbors or real and imagined enemies is in the world marketplace seeking to acquire any technology that might improve their effectiveness. These renegades most likely will be the foes of tomorrow, and the technologies they are after rival those used during

the Gulf War by the coalition forces. The total battlefield dominance demonstrated by the coalition forces, particularly the US, during that war is their goal. Denying that advantage to US forces must be considered an equal priority from their perspective. In this probable future, the Air Force must ensure that we retain a clear advantage in future engagements; i.e., we must continue to achieve the total battlefield dominance we enjoyed during the Gulf War, but very likely against far more technologically sophisticated foes. Total battlefield dominance requires total battlefield awareness, the role of intelligence, and in particular, of reconnaissance and surveillance as subsets of the intelligence process. The Air Force should accept the responsibility to provide that advantage to all future US battle commanders.

Before we examine the probable technologies which will be available, and their effect on the needs of the military, we summarize those needs. We focus strictly on overhead reconnaissance and surveillance, and touch on others only when they have a direct impact on the theme of this paper. Communications is a good example: collecting excellent intelligence is of little use if it cannot be made available to the warfighter in the front lines. We believe that ultimately all user needs will need to be integrated, and a systematic solution defined—systematic but customized to each user class and each intelligence problem. Only in this manner will it be possible to address properly all needs, to incorporate new technologies competitively as they become available, and to stay within what will certainly be limited budgets.

Total battlefield awareness has many components. It includes not only the obvious ability to see the enemy's deployment at all times during an engagement, but a host of other closely related and equally vital elements. Before an engagement, in anticipation of a possible conflict, there is a need for detailed intelligence. This includes at least: maps; a good understanding of the area's geography; the location and potential of weapons of threatening range and capability; weather; the size and location of weapons storage places; and the size and capability of its armies. If these are the "needs," what will be necessary to obtain and maintain total battlefield awareness and the ensuing dominance?

For the Air Force, this portends two critical issues: it will no longer define technology development paths. Instead, it will find itself in the role of consumer of commercial products and services which have been developed for non-defense purposes. Secondly, and given the first assumption, it will need to be prepared to adopt technology at a much faster rate than was required when the pace was being set by the cumbersome DoD procurement system. To do otherwise will mean a second rate system when compared to the commercial field, and a military system second rate to those countries and cartels more agile in acquiring, accepting and rapidly applying current technology.

To function effectively in this world, the Air Force will need to develop methods by which it can stay abreast of the technology rush, and most importantly, effectively and promptly examine and adopt probable applications of new technologies to its roles and missions. It will need to forge working arrangements with industry leaders to keep abreast of new developments at an early stage, and it will need to improve its procurement methods to permit rapid incorporation of desirable commercial developments while optimizing the use of its limited budgets. Inevitably, US government sponsorship of research will become a smaller part of the equation, and diminished coercive clout will accompany that diminished role. Certainly our needed technologies which remain beyond the interests of the commercial marketplace will enjoy the support of

American, and perhaps foreign, industrial development in a manner similar to that of today ... but many of today's NRO-only technologies will become easily available to our foes by virtue of their mass production and marketing through commercial sources. What we need to do for this category of technology is to ensure that our systems are made with tamper-proof components with assured resupply, and that our custom components are designed with the maximum of flexibility to allow interface to and exploitation of the more rapidly evolving "infrastructure" components available from industry. This assured access/performance integration of custom and commercial components and software for collectors, communications and exploitation equipment seems to us the only realistic route to reliable, timely and competitive battlefield information.

Notwithstanding our space-based systems' superiority, timeliness must be improved across the board for battle management lest it be our Achilles' heel: the right information too late is of no value. We suffered this criticism during the Gulf War following the incredible gift of six months of Desert Shield readiness opportunity. A similar situation today would find us at least addressing common standards for imagery communications ... but we need to improve in the following: flexibility in area covered at desired resolution, speed of processing and forwarding the data, and reproduction and delivery of that data in usable format.

We anticipate that day-night, all-weather access to entire regions of conflict will be provided by either: a) long dwell (LDI) good resolution overhead systems using sparse aperture collectors, inflatable primary mirrors, or one of several other geosynchronous orbit imaging concepts or b) a constellation of single-function small low earth orbiter satellites weighing less than 1000 kg and built on a standardized bus. Either approach can provide real-time, high resolution imagery of entire conflict areas. An alternate approach to total current coverage, certainly supportable by the data processing techniques of the VISTAS time frame, is to probe the entire area of interest on a rapid basis, providing update "stamps" into entire regional mosaics, particularly highlighting moving objects or suspicious items. This approach appears both feasible and affordable. Such real-time updating addresses, if done well, the commanders' needs. Advances in automatic target recognition, change detection, fusion of LEO phase data with LDI data, and methods of warning, advising, and archive baseline updating are needed and, we believe, well within reach. Some of these areas are now under early stages of investigation. Here, as in all aspects of the "system of systems," a coordinated, unambiguous, aggressive Air Force leadership is mandatory in conjunction with sensor developers and user developers (NIA, DIA, CIA, NPIC, services) the overall technology and people system can give us the omniscient "god's eye view" of the battlefield.

The system of systems will deliver data for all services. It will be the responsibility of the user community to decide what portion of data processing should be executed by the Air Force as a common service. For example, the Air Force will be interested in aircraft battle damage assessment (BDA) and will provide, during VISTA, automatic (no man-in-the-loop) estimates based on before and after imagery and collateral information. This same capability, and all the imagery and most of the collateral, will be available to support Army and Navy BDA. Should it, or should the systems developed by all services which come together to support Air Force BDA be made available for each service to do their own BDA? Technically, either is possible and supportable.

BDA naturally ties together with precision targeting. In this vein, how should GPS be exploited by the Air Force global reconnaissance and surveillance mission? We anticipate that a successor system to GPS will provide invulnerable US access in beacon geolocation (in 3-space). It is possible that IMINT systems will be a component of such systems for the purpose of target designation, in which case the system of systems would include a bilateral real-time link with radio, multispectral or laser designators and smart weapons on designating and attacking aircraft, missiles, tanks, and possibly, artillery shells. The opportunities for satellite participation in a closed link of sensing and shooting are extensive, but we believe that the VISTA scenario will be limited to capabilities approximating those above, but that those will still be superior to any fielded against us.

4.1.8 Focus for Future Effort

It is appropriate to review history, so as not to repeat mistakes and to learn "what worked." This paper is not intended as a detailed critique of the Persian Gulf War, but only to look at likely future requirements in similar situations. Lessons have been learned, the system of systems is beginning to evolve and new capabilities have been proposed. It is vital that needed improvements not be hobbled by bureaucratic infighting, inertia, apathy, and changing priorities ("Why bother to fix the roof when it isn't raining?"). Individual efforts by the DCI, the JCS, even Congress, to "fix" the problem are meeting with some success. It is mandatory that this system of systems continues to evolve as a team effort; we must not let the lack of a crisis allow any lack of motivation.

It is precisely this high ground as owner of the system of systems that the Air Force should fill. Not by claiming others' budgets or systems, but by designing a plan, a connectivity of all available systems and data bases, an analysis scheme and a dissemination method and system which can be exercised and activated globally, in short order (hours, not months), and which is affordable. From a position of hegemony, the Air Force can then identify solutions to shortfalls, recommendations for acquisitions, and long range plans to maintain US technical leadership and US dominance of future battlefields . Carried to its logical conclusion, such a plan would provide US Forces the infrastructure to provide the necessary "battlefield awareness" with which to achieve dominance and quick victory.

We envision the future imagery system as a matrix of the following:

- *Reconnaissance:* All-weather, day and night, large-scale imaging systems with at least four daily accesses to the conflict region, and more often for tactical purposes
  - Resolution: < 1 meter (Better, on demand, for selected areas)
  - Coverage: > 100,000 Sq. NM Contiguous
  - Revisit: < 4 times daily; < 1 hr. during conflict
  - Availability: < 1 hr. to front line intelligence centers
- *Dissemination:* Real-time access to data bases and archives to at least the Corps echelon
  - Maps

- ELINT
- HUMINT and archival text and historic reports
- Imagery (SAR, E/O, infrared, multispectral, and, on occasion, hyperspectral)

- *Analysis:* Ability by front line intelligence centers to interact with other intelligence processing centers, including those in the CONUS, civilian and military
- *Warning*: Immediate and accurate warning information to all independent US elements at risk, including air, naval and ground forces concerning over-the-horizon launch attack which imperils US and allied forces, noncombatant civilian centers, and peripheral states or cities
  - Aircraft attack

    Size of force

    Type of aircraft

    Possible armaments

    Direction and speed
  - Missile attack

    Number of weapons

    Type of missiles

    Type of warhead

    Direction and speed
- *Weather:* Immediate theater-wide (and farther, as appropriate) microweather in support of ground operations, air operations, space imaging, laser designation

The current accuracy and timelines of weather predictions for attack operations is such that the final decision about the feasibility of using laser designator weapons or other electrical-optical delivery systems must be made by the pilot after penetrating a significant portion of air defense in the target area.

There exist several sensor technologies for improving the measurement of the bottom of clouds and the moisture profiles and other important parameters. The prediction capabilities which use sensor data need better inputs but the prediction technology needs to be advanced and proven reliable in terms of the military operational needs. The current space based sensors are passive instruments in the optical, infrared, and microwave bands. The timeliness and spatial resolution of these instruments can be improved with existing technology sufficient to support many weather needs. However, the prediction models and their algorithms need development. The near-term choices regarding improved instruments and platforms need to be part of a program that involves both research and operation prospective. The NASA and NOAA Programs will be useful but the military needs will not be met without a Air Force involvement.

In the long term space based synthetic aperture radars (SAR) will play a significant role in measuring everything from soil moisture, air moisture, sea ice age and thickness, sea states,

wind profiles, cloud details etc. These radars will be multiple frequency and multiple polarization. These capabilities may be additional features of a space based reconnaissance SAR system. The current activities are primarily research instruments as part of the NASA Earth Observing System or international research instruments. The AF needs to be active in this technology. The Sensor Panels Paper on Global Weather Awareness covers this subject in more detail.

As stated throughout, there are many developments under way which could play an important role in future reconnaissance systems. There is a need, however, to continue to fund enabling technologies which will result in evolutionary improvements to current systems and to form the foundation for the exploration of possible future systems. Some of these are:

- Launch Vehicles—Cost and lift capability (in the sense of dollars per pound) must improve by at least an order of magnitude.
- Materials—Light-weighing satellites need continued development. Some good activities are under way at the Air Force and NASA, but application to intelligence community space systems is lagging. An investment account for Air Force/NRO lightweighting should be created distinct from the regular acquisition accounts to promote advanced materials technology.
- Sensors—Significant continuing funding is required; the NRO is sponsoring some work, as is ARPA and DARO but it lacks focus for the types of warfighting systems which will be needed in the next century. Specifically, work needs to be emphasized in phased array synthetic aperture radar to push the state of the art in high efficiency low cost devices and larger, and multi-dimensional, effective apertures. The commercial world is unlikely to push this—no real application, although we believe that they will begin to explore it as they get into mapping areas of the world which are cloud covered a large part of the year. (The commercial market may be in large-scale radar mapping, which can be done with a single image. Visible and multi-spectral imagery would be used to fill detail.)

  Frequent revisit is a standing requirement. One approach to this is high altitude is long-dwell imagery. Embryonic geosynchronous concepts have shown success in simulation, but the system concept, even for a prototype has not been successfully sold. Other concepts, such as large aperture inflatable optics, and sparse optics need to be evaluated. All of these high altitude concepts will have the advantages of survivability but will inevitably result in expensive systems and therefore must be weighed against the use of small satellites at low altitudes, generally dedicated to a single function as opposed to the multi-mission higher cost systems.

  Foreign imaging of red forces will disclose the effectiveness of their IMINT denial practices. We need to develop E/O sensors which work out to 1.5μ to defeat camouflage paints and netting. We need to provide a narrow-band tuning capability to our E-O systems (even a sub-array would be helpful). We need to implement a thermal imager (everyone thinks we already have it anyway!). While this is unproved, we believe the cost for hyperspectral imaging and the ability to handle its bandwidth (possibly with some onboard processing for detecting particular species, such as CW products) will decrease to the point where a hyperspectral

subsystem is readily accomplishable (most likely, there will also be a US government demand for such a sensor for pollution monitoring).

- Processing—Automated target location and recognition development activities need to be pushed; much work is being done and yet much remains to be done. High accuracy, low false target rates are essential for any technique to be fully accepted in an operational environment. There are no such techniques to find, for example, gun emplacements, mobile missiles in forested areas, underground facilities, and other high value targets. As computer power grows, the power of some of these techniques improves. This is a long road, and we need to keep the pressure on. The commercial world is not likely to be much help on this.
- Dissemination—Compression algorithm development is a key in this area. The commercial world will continue to lead the way. The imagined weaknesses of many of these techniques in a Cold War environment have become an impediment to application where they would be very helpful. We applaud the early work of the NITF forum and urge the Air Force to participate with, and direct the CIO to, move forward more aggressively than currently planned. We particularly urge abandoning the mentality of lossless or "minimal NIIRS loss," encouraging CIO to make common cause with the services in determining actual needed performance to do detection, discrimination, and identification. The way to minimize problems is to work with industry to understand and to possibly improve their robustness and utility—too much emphasis is now placed on equipment compliance with approved algorithms—we need a return to the algorithm development with a focus on user needs, not bits per pixel.

There are several developments in the commercial segment which will have a great impact on the Intelligence business of the future[1]. Although there are many, we'll touch only on those few which have a direct and real near term impact on the issues being examined in the VISTAS study, and which if not taken into consideration will almost certainly degrade the superiority of US forces in the future. They are:

- Commercial Medium Resolution Satellite Imaging Systems

  Within the next handful of months, the first commercial imaging system will become operational and launch a new era in the use of space. The service these systems will provide, i.e. near real time delivery of medium resolution imagery, will have a profound effect on the way nations look at themselves and each other. Already several nations are vying for the services promised, with some wanting outright ownership of the imaging system. While many of the uses contemplated are peaceful indeed—mapping, resource control, agricultural management and so forth-- the potential is there for use in less peaceful areas. Also, as the marketplace develops for the services they will initially provide, there will undoubtedly be competitive pressure to improve the resolution and spectral bandwidth of the

1. Using intelligence in its broadest sense; i.e. readily available information about areas of interest — for commerce, agriculture, education or warfighting.

sensors. This scenario offers two possibilities to the Air Force, one good, the other bad.

The good is obvious: the Air Force and the NRO can piggyback on commercial developments to great cost advantage. It is not hard to imagine that within the next seven to ten years commercial initiatives will rival some of the characteristics of today's intelligence systems, motivated not by government needs, but by the marketplace.

There will be opportunities, at least with American corporations, to influence some of the design features of these future systems in ways which make them more useful in military dress, and the very least, the outright purchase of "off the rack" turnkey systems may be a very attractive alternative to custom-tailored systems. One can envision a situation where a service purchase agreement with one or several of these commercial ventures provides product for use in the more mundane applications of overhead imagery—mapping, for example—and reduce the tasking conflicts on the more capable military and NRO systems. In this scenario, one or more of these "off the rack" systems could be purchased or leased for use in emergencies, as gap fillers or as dedicated tactical collectors when launched into orbits which optimize coverage of areas of interest.

The bad news is also obvious: the bad guys could easily have access to the product of these wondrous systems, and the advantage the high ground has provided us for battlefield dominance would be, at best, shared. But is this inevitable, at least in the next ten to twenty years? We believe the advantage will be with the US for many years, definitely into the VISTA timeframe; the honing and refining of the use of imagery for intelligence purposes has taken over thirty years, and we still have some distance to go before the process can be called well-integrated into our own military doctrine. One needs only look at the Gulf War to see that it takes far more than pictures from space to fight a winning battle—it takes the infrastructure, resources and training to turn fuzzy pictures as viewed by a Monday-morning quarterback into a battle winning strategy (that is, a system of systems!).

- Direct Television Broadcast Developments

The highly successful direct broadcast systems now entering the marketplace are another area where advanced commercial technology offers a capability for distributing information to the lowest echelon in a battlefield. The term "sensor-to-shooter" can become a reality if this technology were to be adapted to military applications. Consider the possibility of transmitting data (maps, pictures, enemy deployments) on demand, to small units, each using an eighteen-inch (or smaller) antenna to receive their orders and situational information. The bandwidth and number of channels available from these systems even now would permit the transmission of tailored data to hundreds of units simultaneously. The communications technology is there; what is not is the archives and control elements to make use of it—the system of systems discussed earlier.

- Detection of Stealthy Aircraft

  It may be possible to detect stealthy aircraft, by using space based transmitters on many LEO satellites in conjunction with proliferated surface receivers, and detecting the moving diffraction pattern signatures caused by interposition of the aircraft platform between space transmitters and ground receivers. This concept is described further in the report of the Sensor Systems Panel.

- Data Storage And Retrieval

  Data Storage And Retrieval commercial technology will almost certainly have a profound impact on our business, and its commercial development is a fundamental necessity for our primary recommendation to pursue a "system of systems." There are a number of development programs under way to increase the capacity of recording media. Laser recording of digital data on tape would increase the storage capacity of data by orders of magnitude when compared with current magnetic tape based systems. Aggressive applications of these techniques are fundamental to achieving the dissemination of current data, rapidly, to the warfighter to give him the "battle awareness" edge necessary to achieve dominance and victory. We can benefit incredibly by the commercial industry across the board, but we need to continue funding for reduction to our applications: we are still the widest bandwidth consumer and we believe we will continue to be at the time of VISTA.

4.1.9 A Vision

One need only look at recent engagements of US troops to define future needs; whether as independent actions, or as part of a coalition; the impact of technology on warfare, particularly that associated with reconnaissance, has been phenomenal. The ability for a battle commander to "see," on a grand scale, regardless of weather or time of day, the deployment of the enemy's troops, his weapons, his lines of communications and his logistics, has been the dream and quest of every troop commander in history. From hills, hot air balloons, early airplanes, and now space, the reach for the advantage of the high ground for observation of the enemy has been a constant pursuit. And it will continue into the future, aided by continued and ever more wondrous technologies. The example provided by technological advantage during the Gulf War is but an omen of the future. And the needs evolving from these technologies will continue to challenge.

These technologies which enable reconnaissance, used interactively, become part of the warfighting. Global awareness through the distributed systems of the US reconnaissance fleet become an indispensable element of the information "high ground" this panel believes is the dominant factor in future war. Whether it is real-time imagery linkage from sensor to shooter, providing automatic targeting, or automatic distillation of order of battle forwarded to the foot soldier or destroyer as icons on soft copy maps or charts, reconnaissance has passed from observation of, to participation in, warfighting.

We see a solution to the requirements stipulated above. It is based on good knowledge of the needs; of the technology now available, on the technology on the drawing board, and on the likely outcome of technology trends, both in government and commercial laboratories. And last

but not least, it is based on the elimination of political and bureaucratic impediments to an acceptable solution.

Some of the elements proposed either are under study or are actually being tested for incorporation into the DoD intelligence system, but most are not. What is still lacking is a clear and accepted vision of what the ultimate goal of all these activities—there is no system of systems design which will meet a stated and agreed upon set of requirements. This would appear to be an ideal role for the Air Force, perhaps the Space Command, as much of what needs to be done involves the use of space.

The following is our top level idea for this system of systems, together with a description of the key elements and a status report of each:

- A well integrated multi-discipline collection system under one authority, with clear lines of authority and of responsibility for each element. This means, of course, the classic elements of intelligence: HUMINT, open source, ELINT, and IMINT. For the purposes of this paper, we've concentrated only on IMINT, and primarily from space, and touched on other venues only when they were necessary or they complemented our solution. At this juncture, we've not addressed ownership, only capability.

Its key elements are:

- A robust, full-time, multispectral high and medium resolution imagery collection system, with world wide access on an unrestricted basis. At least four times a day revisit time of any geographic area, and near-real time transmission of date to command centers in the CONUS and at designated CINC's.
- A robust, world-wide access surveillance system capable of detecting missile launches into the exosphere and high altitude high speed aircraft. This system should be capable of enhanced attention to specific geographic areas in response to crisis. Alerting information from these sensors should be available to the threatened force and to counter forces in less than one minute.
- A quick reaction surge collection system consisting of medium resolution synthetic aperture radar satellites to provide day and night and all weather imaging capability for tactical purposes. These satellites would be launched into inclination planes which optimize revisit times in the geographic area of interest, and which complement the full-time, world wide collector system. Two, three or four of these satellites would be deployed, depending on level of conflict, sophistication of foe, and geographic region. Alternatively, permanent deployment of such a constellation of low-cost collectors.
- A worldwide intelligence data super-archive accessible from anywhere in the world through a secure, broad-band communications system. This super-archive would be accumulated during periods of relative peace, using all source intelligence. It would be managed jointly by the civil intelligence community and by the DoD. To be completely useful during times of conflict, the archive would be generally available for training and for use in weapons development. Collection of data

from areas of potential conflict would intensify as the world situation warrants. This would maximize the use of the relatively reduced role of the National Collectors. The archive would contain the types of data required by the battle commander to have the "awareness" described above, including maps, annotated imagery, geographic information, weather, communications lines, political data, etc. The archive would be accessible to lower echelons, as determined and permitted by the battle commander, and limited to their area of interest. The data available from the central archive would be supplemented and enhanced by organic assets, as they deploy and begin operation (ground reconnaissance, airborne assets, tactical imaging satellites). Data acquired by organic assets which enhances or updates the archive data would he incorporated into the archive.

- An integrated data management and tasking system which would control this system of systems. Joint military and civil control during peace time, and military control during times of conflict.

"Owning the high ground" of space is indispensable to the country which leads the world. Our current ownership will be eroded by the availability of commercial systems, but our loss will primarily be in raw data comparability. We need to maintain an edge on wavelength, bandwidth, area collection rate at good resolution, flexibility of access, timeliness, and revisit ... but ownership implies value, and value can be owned outright by us during VISTA through a system of systems which optimally manages data, converting it efficiently to information, and merging, analyzing, and disseminating the appropriate subsets of that information to our users as world-class operational intelligence and battle support data in a timely manner.

4.2 Missile Warning and Space Surveillance

S. M. Tennant, W. Mann, G. Canavan

4.2.0 Introduction

With the Soviet development of ballistic missiles capable of delivering nuclear warheads in the 1950's, it became apparent that in order to achieve effective nuclear deterrence it was necessary to have warning to preserve the National Command Authority and to assure retaliatory strike with our complete nuclear strategic forces including the airborne leg of our nuclear triad (aircraft, land based ballistic missiles (ICBM)and submarine launched ballistic missiles (SLBM)). While the Ballistic Missile Early Warning System (BMEWS) radars were under development in the late 50's, the need was for early detection of ICBM and SLBM launches to provide adequate warning time and dual phenomenology to eliminate false alarms and provide accurate attack assessment.

The Air Force undertook conceptual development of airborne and space based ICBM warning systems utilizing IR in 1958. The airborne approach was based on nuclear powered aircraft capable of long duration high altitude flight for detection of ICBM or SLBM launches. The nuclear airplane approach was subsequently discontinued because of the large size of the nuclear reactors which made the aircraft impractical and too costly as well as the safety issues associated with the reactor.

The space based concept was pursued with the MIDAS program which was started in 1960 and was launched in 1963 and demonstrated the utility and potential of a space based IR sensing missile warning system. Based on data acquire in the MIDAS program and the RM experimental satellites that acquired IR background data, the Defense Support Program (DSP) was initiated in 1966 and became the United States' global early warning system capable of detection of both SLBM and ICBM launches. Because of the possibility of glints off of cloud edges and other system noise, the need for second phenomenology verification was met by the BMEWS and Pave Paws radars.

Based on the MIDAS results the DSP I satellite was developed, launched an initial operations took place in 1970. This was followed by the improved phase II satellites in the period from 1974 to 1980. As part of the evolutionary improvement of the DSP, the Sensor Evolutionary Development (SED) program was undertaken which increased the number of short wave IR (SWIR) detectors for below the horizon (BTH) coverage and added mid wave IR (MWIR) detectors for limited above the horizon (ATH) coverage. This provided improved capability and new phenomenology data of significant value to follow-on system developments. The SED sensor, along with onboard data thresholding and cooling system improvements formed the basis for improved DSP satellites which have been acquired and launched from 1985 to the present and are planned to be the principal missile detection, track and prediction system, with the last launch in 2003.

We now have a missile warning system based on radars and satellite SWIR sensors. The radars are capable, if old, but are supported by software that is outmoded and an analysis system that is not physically based. Thus, they generate bothersome levels of false alarms. For many threats e.g., SLBMs, their indications can be quite misleading. It would be very expensive to modify them for the attack assessment for which they are tasked, but it is not clear that this

mission is appropriate for future threats. They key issue is whether radars are still needed for dual phenomenology. The future development of radars is unclear. If they are not modified, they will become a bit of a military museum. If they are, it should be in software and for a warning rather than an assessment function. Such an upgrade is likely only in the event of a renewed Russian threat. Otherwise, it would be appropriate to maintain only a few sensors such as the FPS-85 at Eglin and perhaps PARCS for space surveillance.

The satellite missile warning systems are also capable, if based on decades-old technology for largely single band SWIR detection. They use linear arrays of detectors with large pixels designed to produce adequate S/N against large strategic missiles; however, those arrays have provided a very useful capability against orders of magnitude smaller theater missile signatures. There are some (non water producing)fuels they might not see, but that has not been a problem yet. Their main weaknesses are the delays between revisits, which cause them to miss transient events and take tens of seconds to establish tracks. Offsetting that is the ability to integrate the outputs of several satellites for stereo and range, which makes those tracks very accurate. Their GEO positioning makes them survivable today, although their command and down links are accessible. In the long term, that could change.

4.2.1 Strategic Defense Initiative (SDI)

The SDI as initially envisioned was to be a nearly leak proof multi-layer defense against massive Soviet ICBM and SLBM attacks through combined boost phase, post boost, midcourse, and ground terminal defense layers.

The original boost and post boost defense concept required a very advanced missile warning system which detected launches and maintained precision track on each missile in a mass raid through booster and PBV burnout in order to provide near real time boost and post boost phase fire control data to a constellation of space based interceptors (SBI). These requirements resulted in the high altitude Boost Surveillance and Track System (BSTS) with very large optics, and very large and complex mosaic or scanning focal planes along with unprecedented levels of onboard signal and data processing.

The cost and risk of BSTS development, coupled with the challenge of guaranteed distribution of fire control data to thousands of interceptors, was a significant factor in the decision to substitute the more autonomous and distributed Brilliant Pebbles interceptor concept. Attack warning and authentication were still required with Brilliant Pebbles but were treated as part of the normal Air Force missile warning mission.

Subsequently, the SDI mission was scaled down from global protection against massive attacks to a National Missile Defense (NMD) against small or accidental ICBM or SLBM attacks and Theater Missile Defense (TMD) as part of a Global Protection Against Limited Strike (GPALS) mission requirement. As this trend continued, the National Missile Defense Program was relegated to a technology readiness program, and the SDI (later BMDO) program shifted almost entirely to defense against theater ballistic missiles.

4.2.2 Desert Storm and its Aftermath

Desert Storm focused attention on the value of detection, track and timely warning message dissemination for SCUD class missile attacks. The DSP was able to detect most of the launches

under the near ideal night time conditions but lacked the stereo processing and communications needed to provide accurate and timely warning messages.

The Army and Navy had gone directly to Aerojet, the DSP sensor and software contractor, to perform a Tactical Surveillance Demonstration based on their proposal on how to process tactical data. This program was successful in demonstrating that commercial hardware and relatively straight forward extensions of the DSP software could be used to process data coming down directly from DSP satellites in view of the ground station to provide missile launch detection and track in near real time. With more than one satellite in view at one time, this system could process stereo data to get more accurate track and warning messages. This demonstration resulted in the Army and Navy JTAGS system which now has been deployed with Army field units and on board Navy ships.

In March of 1992 the Air Force initiated the Talon Shield program that is similar to the JTAGS but is capable of fusing all data that can see the target to provide more accurate launch and impact point determination. The operational version of Talon Shield, ALERT, is in operation and is located in Colorado Springs and uses established communication networks to disseminate data to tactical users worldwide.

It should be possible to add multiple wavelength detectors in the SWIR, MWIR, and visible for better detection and discrimination. It would be desirable to shift from linear arrays of detectors to large staring array focal planes. However, that shift has been predicted in each of the last three decades, but has been thwarted in each because of problems with yield and size. Moreover, if staring focal planes were purchased at the price of stereoscopic viewing or of larger detectors or lower S/N, that would represent a step backwards in terms of tactical and strategic utility. Such a ranging capability might be retained by the addition of a laser or radar ranger, but such sensors have progressed slowly in their development for the last three decades, and are difficult to implement from GEO.

Much of the pressure for a shift to staring systems comes from increased concern with theater threats. However, such threats could be addressed more simply by additional AWACS aircraft, which appear to be the economically appropriate solution for single-theater threats. If that option is selected, the competition for funds could further delay or eliminate the Brilliant Eye (BE) option. On the whole it would appear that only modest improvements in detectors and electronics and slippage of advanced systems is likely in the next decade, largely due to lack of a really compelling technology for upgrade.

The midterm developments are likely to be what are now thought to be the near-term programs: more bands, multiple satellites at lower altitudes, large staring arrays, and active ranging sensors. There is a natural synergism between them. Using multiple satellites at lower altitudes permits them to use the largest effective arrays with detector size to be designed for the targets of interest. Active rangers restore range and hence accurate trajectories without stereo viewing. Space-based radar for all-weather search, detection, and track would then be a natural adjunct to both the other space sensors and the limited AWACs assets. With that suite of sensors it should be possible to perform much of the threat assessment, put trajectories into GPS coordinates, and possibly to direct some intercepts from space. Note that ballistic and cruise missile threats to both Allies and CONUS should emerge in force in about this time frame, so that these should be just the proper suite of sensors and weapons to address them.

The long term can be defined simply as a period beyond 30 years, as a time when technology will permit anything we can envision doing today, or as a time when we will have serious and competent adversaries for the control of space. Each definition leads to the conclusion that space is likely to become a place of greater and more lethal competition. In such a competition, non-stationary placement is likely to be an advantage, smaller and more numerous warning satellites are likely to have a distinct advantage. Hardening and decoys will be essential; self-defense capability may also be needed.

All of these capabilities will be essential in protecting the satellites' ability to perform their warning and assessment mission, which will become ever more important. There will not only be conflict in space; there will also probably be serious conflict on the surface of the Earth and in the air. Space sensors are the appropriate means for detecting and assessing all of them. Their assessments will have to be fast and fully integrated into those of ground and aerospace forces. This would appear to be the period in which those forces would have to be fully integrated to achieve their full-and required-potential. Overall, there appears to be a basis for limited, technical developments in the near term and more sweeping, but still essentially technical developments over the mid term, leading to fundamental developments in the long term that could support important new military capabilities.

4.2.3 Space Surveillance

The present space surveillance system is comprised of a number of ground sensors including radars and optical devices, some of which are in the United States and others are at foreign bases throughout the world. These include the Navy's NAVSPASUR radar fence in the southern part of the CONUS, imaging radars such as HAYSTACK, HAX ALCOR, MMV, and all the Space Surveillance Net narrow band radars. The optical devices include imaging, photo/polarimetric and conventional telescopes using electronic image tubes. The data from these devices are fed into Cheyenne mountain in Colorado Springs where orbital parameters are calculated for each of the cataloged items and sensor tasking is prepared and sent out to allow continuous update of the catalog.

The current space surveillance system is based on a number or radar and optical sensors. The radars were generally built for other purposes and have inadequate calibration for this task. The optical sensors have marginal intrinsic resolution and dated focal plane technologies. The radars have biases and resolutions that lead to the need for frequent manned intervention, and hence operation that is expensive in terms of both money and people. Both are supported by dynamic models that are based on inadequate physics that has been ported blindly from earlier computers in a manner that is not designed to take advantage of modern architectures or hardware. The result is an expensive and inaccurate surveillance system that is ripe for change.

4.2.4 Space Surveillance from Orbit

The original SDI multi-layer defense concept against massive strategic attacks employed an above the horizon space surveillance equivalent to BSTS called the Space Surveillance and Tracking System (SSTS). SSTS was dropped along with BSTS when the mission was de-scoped to GPALS and the Brilliant Eyes concept was introduced in its place to detect, discriminate, and hand over midcourse targets either to Brilliant Pebbles for early midcourse intercept or to ground

based defense for late midcourse or terminal intercept. A constellation of 20 to 30 small (around 1500 Kg) Brilliant Eyes satellites is required to perform this mission.

The BE midcourse mission is performed with a very narrow field of view (less than 1 degree) tasked, staring, visible and M/LWIR sensor. The current LEO flight test program will demonstrate intermediate wave bands adequate for detection of warmer, shorter range theater missile midcourse targets. There is also a design and an unfunded flight test option to add additional cooling and a longer wavelength IR focal plane to provide capability against strategic missile targets which are cooler and have less radiant energy.

The Brilliant Eyes system also carries a much smaller (in aperture, weight, and power) below the horizon scanning sensor to acquire missiles during the boost phase and provide a precision internal hand over to the narrow field of view tasked tracking sensor. The BTH acquisition sensor has a "horizon to horizon" field of regard but was originally designed to be operated in a tasked mode in the sense that it was assigned to detect and track launches only in a "hot spot" 1500 Km in diameter. During the 1994 SBIR study it was shown that the BTH sensor could be operated so as to detect and track launches in its entire (horizon to horizon) field of regard with minimal weight and power increases. The "horizon to horizon" capability would allow the BE system to do the missile warning mission as well as the midcourse tracking and hand off to the BMD element. This "horizon to horizon " capability is included in the BE flight demonstration system and is the current SBIR LEO baseline.

4.2.5 Current SBIR Plan

The Space Based Infrared System (SBIRS) Single Acquisition and Management Plan (SAMP) states that the SBIRS will be a consolidated, cost-effective, flexible system that will meet United States Infrared space surveillance needs through the next 2-3 decades. The SBIRS, as approved by the Defense Resources Board (DRB) consists of a ground processing segment and a space segment. The space segment contains a High altitude component in GEO and HEO orbits, a LEO flight demonstration system, and, assuming a 2000 decision to deploy is made, a Low element in (LEO). The ground segment contains mission processing and communications systems, as well as support infrastructure, to support integrated SBIRS (DSP, GEO/HEO, and LEO) operations. This SAMP has been prepared to cover the acquisition of the High elements and two increments of the ground segment, for DSP and High elements operation. Though it is part of SBIRS, the flight demonstration system is being acquired under a separate contract. After a LEO deployment decision, the LEO element and any associated ground increment will be acquired as part of SBIRS and the SAMP will be updated as necessary.

4.2.6 Space Surveillance Upgrade Planning

The computer portion of the surveillance network could benefit most from better calibration. The next step would be better models and computers that could make better advantage of the many observations they can provide each day. Radar upgrade is essential, in that the required elements of orbits cannot be attained without active systems. That is particularly true of objects at GEO, for which the contribution from Haystack is important and should continue. However, that does not necessarily require a large number of radars. A few well-calibrated radars would appear to be much more valuable than many ill-calibrated ones.

The optical systems could benefit most from better operation. The current mode, which incentivizes the greatest number of observations rather than the most useful observations, actively impairs the effectiveness of their use. The next step would be the replacement of current TV tube focal planes with CCD detector arrays, which with the step indicated above could improve the accuracy of observations by about an order of magnitude. With improved computers and atmospheric density models, that would permit a much greater fraction of observations to be made automatically, which could reduce manpower costs by a like amount.

It should be noted that the focal plane upgrade indicated should probably take place in two steps. The first would place the 2K x 2K (4 million detector) visible CCD arrays already tested into current GEODSS telescopes, which would improve current capability by about an order of magnitude. The second would probably involve substituting 4K x 4K arrays (probably generated by butting four 2K x 2K arrays together), which would improve performance by about another order of magnitude. The development of this second generation of CCDs would push that technology about as far as appropriate for ground-based telescopes, and would also develop the CCDs needed for space-based telescopes, which would be the next logical step.

These steps are simple, but they illustrate that a number of modifications that are needed for operational effectiveness could-for a very limited amount of money-complement a number of technologies that are ripe for application to significantly improve an badly needed operational capability. Radar measurements will continue to be important in the mid term. An upgrade to Haystack may be necessary, given the increasing fraction of the catalogue at GEO. A dedicated radar fence upgrade may also be needed for low-altitude satellites.

It appears that in the mid term, two space technologies will be both needed and ready: optical and LWIR focal planes for sensors in space. The former is for very distant, sun-lit objects at GEO; the latter is for the bulk of nearby but cooler objects and for the discrimination of transient satellites. Satellites, computers, and focal planes have now progressed to the point where it should be possible to keep track of much of the catalogue from space without the need for ground-based telescopes. From space, satellites can measure objects that are several visible magnitudes smaller than they can from the ground, which also makes it possible to extend the survey to fainter objects and search for stealthy intruders. There is no corresponding advantage in space-basing for radars.

In the long term, the space surveillance system will have to search for objects that are more numerous, maneuvering, stealthy, and potentially hostile. For satellite-based sensors, the greater number of objects is a direct but probably manageable problem.

Maneuver cuts two ways: if it is seen, it is a cue; if it is not, it is the occasion for a rapid, wide-area search. Stealth impacts the search rate per satellite, and hence the number of satellites that will be needed. Hostility impacts hardening, maneuver, decoys, and other survivability measures. That would appear to force the satellites for space surveillance towards those for missile warning. To the extent that this happens, the two constellations could merge into a single constellation of sensors with a large number of small satellites that could look in all directions and maneuver enough to survive to do so and perform essential assessments.

4.2.7 Space Debris

The catalog in 1994 contained approximately 200 active items and 5500 inactive items in the near earth orbit. In the deep space portion of the catalog there were 200 active and 1200 inactive objects. The present capability for tracking space debris in LEO is 10 cm. With the advent of the Space Station there has been discussion for the need to track objects down to 1 cm size and provide accurate prediction data at least two orbits ahead in order to allow the station to maneuver out of the way. It is estimated there is approximately 100,000 debris objects equal to or greater than 1 cm and thus this represents a substantial increase in the tracking and accurate prediction requirements.

Debris is left from putting satellites in orbit. It is made up of dead satellites and pieces of man-made junk. It would appear that the latter dominate the natural environment down to sizes of about 1 cm, which is also about the largest size against which it is possible to shield against impacts with acceptable penalties.

Debris objects down to about 10 cm in diameter are maintained by the USAF Space Command in a catalog, which is updated by optical and radar measurements. Objects smaller than 10 cm are hard to measure; the catalogue's completeness is very poor for them. The only detailed survey by size and altitude is NASA's measurements with Haystack, which do not agree with the catalogue to better than an order of magnitude.

The likelihood of a piece of debris of any size colliding with an Air Force satellite is so slight that it is apparently appropriate to ignore it and self-shield against the threat, although it would be useful to know if simple and inexpensive protective measures could be developed. For the Space Shuttle, which is several orders of magnitude larger and which contains persons, the threat has be assessed to be on the order of 10% over 10 years, which is bothersome. Moreover, NASA scientists have estimated that the impact of one piece of debris on another could start a cascade of collisions, which could make all of low Earth orbit (LEO) unusable. This estimate is based on guesses at certain key parameters-primarily the number of objects produced per collision-which have not been verified experimentally. These uncertainties have made the predictions on semi-quantitative. They do not provide a useful indication as to when the problem might actually become acute.

Debris forms a background that interferes with the performance of space surveillance, so the first step would be to implement the improvements in space surveillance outlined above. CCD sensors in space would eliminate much of the bother with large objects. An upgrade to Haystack that would permit it to see 1 to 10 cm objects better would also be a useful extension of current cataloguing as well as a useful adjunct to later mitigation and reduction efforts.

The key issues needing work in the next decade appear to be cascading, mitigation, and reduction. Better analytical models of cascading could probably be developed, but the main uncertainty is the number of pieces produced per collision, which is at present primarily an experimental matter. Fortunately, gas guns with the required velocities are now available, so the needed experiments could be performed in several laboratories inexpensively. With that information, it should be possible to say whether or not cascading is a problem. Then, or in parallel, it would be possible to study the changes in operational procedures needed to mitigate the threat as well as the techniques that would be available to remove the debris.

What is done in the mid term would depend on what comes from the developments of the previous decade. If good, cheap hardening is possible, it should probably be implemented on new satellites. If not, the Air Force should continue to self-insure, and NASA should reassess the Space Station. If experiments and modeling indicate that cascading is not a problem, no further action is required on debris mitigation and reduction. If it is, experiments should be performed to test prototype measures. For mitigation, those measures take the form of limitations on operations, which are simple to formulate, if painful to implement. For debris reduction, the measures are not well defined, let alone tested.

The long-term solution to the debris problem depends on what comes out of the mid term. If cascading isn't a problem; neither is debris, to first order. If it is, the response to debris will be a more careful use of space that emphasizes fewer fragments and explosions-both of which would constitute an extension of current trends.

4.2.8 Planetary Defense

Another potential mission for space surveillance is planet defense, that is cataloging those comets and asteroids that have earth crossing orbits and at some time in the future pose a threat of striking the earth. This requirement poses a stringent requirement in terms of sensing in that some of these objects are far distant from the earth during a large part of their orbit. Also because the nature of these bodies is not well understood it is desirable to perform a fly by or impact to determine the composition and to better evaluate the options for deflecting or destroying the object to avoid collision with the earth.

4.2.9 Future Prospects

The missile warning system suffers many of the similarities with the launch vehicle problem. The follow on systems have an architecture that while they provide substantial improvements, they are immensely expensive and the threat does not urgently justify them. The FEWS was an evolutionary development of the BSTS and incorporated many of the high risk technologies of elaborate focal planes, demanding stabilization and large amounts of on-orbit signal processing and data computation. While the Air Force Space Command stood behind it to the end, it lacked credibility with OSD and the Congress.

The current SBIRS approach is far more credible in the sense of using the same sensor on the HEO and GEO satellites and a GEO bus based upon cost-effective use of existing bus production line facilities and practices. Nevertheless there is the nagging question of the need for both GEO and LEO systems since it appears both the missile warning and the midcourse tracking requirements of BMD could done from LEO. The principal stumbling block with the LEO system is the number of satellites that have to be controlled and with the present antiquated satellite control approach the Air Force is using, which looms as a major cost item. However multiple satellite distributed type systems are the wave of the future and the Air Force is going to have update its satellite control capability with modern data processing equipment and software to make this mainly an automated operation requiring only minimal manning.

4.2.10 Enabling Technologies

Enabling technologies include focal plane developments that extend the sensing of LWIR with minimal required cooling and development of light weight efficient cooling devices. There

is the need for fast CCD read outs that allow for rapid tracking of many objects. The trend toward low altitude multiple satellite constellations will put a premium on autonomous satellite operation including the management of redundant subsystems. Because of the seriousness of space debris, future injection stages need to be designed to preclude explosions from residual fuel and more thought needs to be given to deorbiting stages and spent satellites or boosting them into high benign orbits. If clearing space debris becomes a necessity, high powered pulse ground based lasers may be required. These can only be effective with an accurate pointing system which may require use of LIDAR technology. Fundamental to all future missile warning and space surveillance capability will the ability to handle ever increasing volumes of data in complex predictive computations.

4.3 Space Communications

Jerry O. Tuttle

4.3.1 Introduction

The satellite communications (SATCOM) architecture and spacecraft design for the period commencing in 2015 should be determined now and taken into consideration inter alia:

The volcanic eruption of emerging technologies

The explosion in bandwidth

The insatiable thirst and demand for information

The ever increasing demand and competition for spectrum

Commercially available and planned communication satellite constellations

Direct broadcast and asynchronous mode of operations

The commercialization of space

The role for and potential of distributed satellite systems

A changed and broader scope profile for potential enemies

The maturation of Information Warfare

Unique military survivable and enduring satellite communications requirements

The realization that the indigenous satellites at that time have not been launched.

Salient communications capabilities will include global:

Person to person connectivity

Include high speed digital data, voice and multimedia

Provide direct access to vast depositories and reservoir of information, and

Will enable virtual reality and computer simulation, rehearsal and event execution.

This SATCOM architecture must be flexible, scaleable, fault-tolerant, reconfigurable and user simple, the result of a cooperative effort by DoD, the services, NSA, NRO, DOE, DOC, DOT, NASA, the National Laboratories, industry and our allies, and viewed as complimentary to and an extension of the international fiber optic grid. Major changes must be made in space communications assignments vis-à-vis the current MILSATCOM channel allocations. Those users that can reside on fiber optic arteries must do so, freeing the bandwidth on orbit for use by the mobile, tactical users.

Earth will be a "wired world" whereby anyone, anywhere, including soldiers, sailors and marines, and airmen, can carry crackerjack size devices and communicate with any location in the world via multimedia and in any trackless, featureless environment know their spherical position within meters (actually centimeters) in any weather, day or night. It will be an era when parents, relatives and loved ones of every soldier, sailor, marine and airman can sit in their

living rooms and observe real time, in three dimensions, the total environment in which they are operating. This comprehensive situational awareness will be viewed in dens and bars around the world at the same time as the on scene commander, the one with the ultimate responsibility, and will have an indelible effect on how wars/conflicts are waged. Time will no longer be measured in years, months, days, hours and minutes, but nanoseconds. Information will be tagged with GPS time accuracy that will serve as its primary and basic attribute. In fact, all communications will have GPS position, time and velocity vector superimposed upon every transmission to enable all in the net to know the others exact position and their relative position.

4.3.2 Enabling Technologies

Because of great improvements in switching technology, digital signals processing, fiber optics, wavelength-division multiplexing, and digital radios, bandwidth is expected to increase from five to 100 times as fast as computer speeds. Within a year, 10 gigabit-per-second communications arteries (OC-192 trunks) will be a reality and the available bandwidth will continue to expand at an exponential rate. Today, 700 separate wavelengths can be sent over a single fiber-optic thread and in the near further it will be possible to carry 2.4 gigahertz on each wavelength which will result in more than 1,700 gigahertz on every fiber thread. Within a decade it will be possible to send 10,000 wavelength streams down a single fiber thread and emergent erbium all-optical broadband amplifiers will permit communications transport at the speed of light. Fiber circuits will provide almost unlimited bandwidth, greater reliability, less noise and at modest cost. The requirement to convert electronic pulses every 35 to 50 kilometers to be amplified and regenerated will be but romantic memories. Today lasers exists that are powerful enough to send signals across the Atlantic without amplification. And, although there will exist a plethora of trans-oceanic fiber optic cables and every theater CINC will be serviced by multiple, alternately routed fiber optic cables, restoreal cables could be laid if necessary. Cables can be laid between New York and Great Britain today in six days and this time will undoubtedly diminish in the future. This global fiber optic grid will have a profound effect on the space communications architecture, where functions will be performed and by whom. Reportedly, 98 percent of the world's major cities will be serviced by fiber optics by the turn of the century, greatly influencing what the military commanders will target and significantly complicate intelligence collection.

Asynchronous transfer mode (ATM) communications will usher in greatly expanded bandwidth that will accommodate simultaneously voice, video and data and bring a new dimension to C4I for the Warrior. Bandwidth of 2.4 gigabits is available now and will increase as the technology matures, spurred in the private sector by commerce and the multimedia entertainment enterprises. It potentially will provide every household around the world home TV entertainment via satellite. This capability unto itself would enable a subliminal form of Information Warfare.

The performance of microprocessors will continue to escalate exponentially and the power of these computers will not only be their individual computing capabilities or data storage (14 gigabytes of RAM today with 64 bit technology), but their ability to access phenomenal network computing capability and network data storage. Video digital "pumps" will receive and distribute enormous serial bit streams to massive parallel processors for transaction computations. Span servers will permit the interchangeability of optical media, regardless of the operating systems

and the portability of objects as easily as structured data today. This will enable multimedia with all of the wonders of color graphics, high resolution satellite imagery and video.

As we enter the age of bandwidth measured in billions of bits per second, we must remain conscious that microprocessors, as marvelous as they are, still are rated in millions of instructions per second. Experts disagree on how close we are to the "limits" of Complementary Metal Oxide Semiconductors (CMOS) technology. For years, it has been predicted that the semiconductor industry will hit the limits of CMOS fabrication. So far we haven't hit these limits and in the near term increases in performance can be achieved by making things smaller, denser and faster. Chip density doubles every 18 months. However, as .05 microns (particles smaller than the size of a virus) are reached around the turn of the century, we will have reached the limits of the number of transistors (approximately 100 million) that can be put on a chip with current technology. The dissipation of 80 watts of power for 100 million transistors would have presented a challenge, but industry has migrated from 5.5 volt chips to 3.3 volt ones enroute to 300 millivolts. The smaller chip voltage needs, reduces the heat to be dissipated and microprocessor power requirements, enabling faster, cheaper and cooler devices. Smaller devices closer together at lower power is the key to speed and the faster the transport the lower the noise.

Industry promises to increase peak clock speeds by a factor of five in the next two years and chip performance by factors of several hundred. Chips at the end of 1995 will function at 1.2 gigahertz and perform as many as 400 gigabits transactions per second

Research is being conducted on multi-billion transistor chips, described as gigascale integration (GSI). GSI will be governed by fundamental, material, device, circuit and system physical limits. Soon teraflop microprocessors will be available in desktop variety providing teraflops of power for processing terabytes of data. These lower powered microprocessors with unfathomable performance will open entirely new vistas of generic opportunities for applications on orbit.

Over the past 35 years minimum feature sizes have declined by a factor of 50 to 1, switching energy of binary transition has decreased by a factor of 10 thousand and the number of transistors per chip has multiplied by 50 million. Yet, the price of a chip has remained virtually unchanged and its reliability has increased manifold. One can confidently predict continued leaps forward and perhaps an increase in pace in the future. Uniprocessors will give way to symmetric multiprocessing and massive parallel processors.

Communication satellites in the year 2015 must incorporate these and other emerging technologies to ensure bandwidth is available to provide the warfighters the information that they will require. Massive onboard signal processing should be a major factor in the design of communications satellites to improve the signal to noise ratio and effectively increasing the power output and ameliorate the power aperture problem for the mobile, tactical users with small antennas. This quantum leap in processing capability will enable communications 30 to 40 dB, and possible greater, below the noise level. This spread spectrum, frequency agility mode of operation employed in the past, with the attendant trade-off in bandwidth, to achieve an anti-jam margin of protection, and low probability of detection/low probability of intercept communications can now permit users to operate on top of each other without interference, preserving precious frequency spectrum. This feature takes on ever increasing importance as

the competition for frequency spectrum becomes excruciating and spectrum becomes a lucrative source of revenue and takes on greater significance during this period when military used frequencies are the most vulnerable.

Small, light weight, rugged, affordable, broadband, high gain, electronically steerable antennas that are able to access multiple satellites, in different frequency bands, in different parts of the sky simultaneously must be designed and fielded for the mobile, tactical users. The single frequency, mechanical, parabolic antennas must become footnotes in the history of satellite communications.

Voice activated, controlled and operated computers are available today. Soon one will be able to communicate via polyglot computers that will translate and provide language error correction for duplex communications with most nationalities in the world. Real time transliteration of text in over 100 languages exists today and by the year 2015 will include all significant languages in the world.

Smart software will manage vast information networks far too large and complex for human control. Using genetic algorithms, software will adapt and evolve to solve changing problems, without new programming.

These enabling technologies are of mythical proportions, but are within the realm of sober scientific reality and will provide opportunities that only the most sagacious can envision. Historically, we have been quixotic in our near term estimates and myopic in predicting our more distant achievements.

4.3.3 The Anatomy of Space Communications in 2015

The tenets for the satellite communications architecture for the year 2015 will be the same as for any information system today and consist of six essential features. The system must prescribe single data entry and be:

Seamless—Information at the user's fingertips, without any air-gaps, transparent to the user.

Open Systems—A common operating environment and standards, i.e., "building codes".

User-pull—The user must be able to dynamically construct his own information domain, i.e. administratively, geographically, prarametrically, temporally, etc., so that he gets only the information that he needs, when he needs it, and in the form that he desires. We drown in data, yet thirst for information and knowledge.

Multimedia—If mathematics is the queen of the sciences, then colored graphics, images, and video are the royal interpreters and must become inseparable partners of traditional voice, facsimile, narrative messages, etc.

Scaleable—A building block system that can be optimally tailored to serve the user's needs and be able to expand in performance and capability at least linearly and preferably exponentially.

Multi-level Security/Trusted Systems—A highly desired feature today and an absolute requirement tomorrow.

There will be universal and easy access to any person, organization and enterprise in the world and to vast sources of information for personal, vocational and occupational use for commercial, educational, environmental, public services, health care, disaster relief, military, etc. benefits. This proteus of all information systems will be a ubiquitous network of networks composed of both terrestrial and space based communications systems and be transparent to the users. This hybrid communications system will provide "fiber-like-service" and optimum routing over every variety of communications satellite. Network management will be of such complexity that it will necessarily be automated and provide adaptive and alternate routing based on the bandwidth on demand requirements and the merit of the "system of systems", down to the pixel level, with a bit error rate of less than one in a 10 billion. All circuit will have full automatic standby circuits and have continuous monitoring for determining circuit status. This heterogeneous network of networks will embody inter satellite connectivity, via cross links, first within the same constellation and orbital plane, but eventually between satellites in different orbits and in different frequency bands. This decentralized satellite communications network will interconnect low and medium-Earth-orbiting satellites with geostationary satellites to form a powerful and extraordinarily high-capacity holistic satellite communications "system of systems" that will seamlessly interface with terrestrial communication networks to form a global multi-media information system. The satellite communications architecture will provide a seamless extension of terrestrial networks and provide connectivity to sparsely populated and remote areas not now serviced by fiber optics and the regions where the military is most likely to operate.

The need for dedicated military systems will diminish and increased dependence will be placed on redundancy for survivability. Today, over ninety-five percent of Defense and Intelligence Community voice and data traffic uses the public telephone system and this amount is likely to increase. Security, reliability, and availability, the traditional reasons for dedicated military communications satellites will be routinely attained in commercial systems by volume, diversity and proliferation of all transmission and processing means. The future satellite communications revolution will be driven by commercial developments and led by the explosion in bandwidth and its plummeting cost. In crafting the satellite architecture for the year 2015, the technical culture and inculcated mindset of bandwidth scarcity must be overcome. Neo-Luddities who would deter the rapid growth of this global information network must be neutralized. It is the building of the Global Information System for the 21st century that is the task at hand and not clinging to the 20th century antediluvian procedures and systems.

Commercial satellite communication bandwidth assignments and channel arrangements that historically accommodated voice and television communications, will increasingly migrate to handling data, imagery and multimedia communications. Even the Ku band which is currently focused on over land and high density populated areas, will give way to more universal worldwide coverage. Media servers will act as a multimedia library that stores, retrieves and manages all type of information, including video, audio, images, text and relational data. Interactive global television will be common place, including the Joint Task Force Commander's forward command post.

(Following two paragraphs are taken from Mr. Ivan Bekey outstanding and visionary paper.)

Extraordinary demands on the frequency spectrum will require wide use of frequency-reuse technologies and procedures such as numerous simultaneous spot beams with very small footprints, attained with antennas or arrays hundreds of meters in diameter aboard GEO satellites. Similar technology in lower-orbit satellites could be used to drastically reduce the transmitter power required for portable terminals, as well as reuse the frequencies for spectrum conservation. Insatiable appetite for more spectrum driven by market forces will force expansion into higher and higher frequencies, with their attendant increased bandwidth. Millimeter, infrared, and optical wavelength communications will become necessary for most fixed up and downlinks, utilizing geographical diversity to prevent outages due to weather.

The Global Information Infrastructure will depend heavily upon myriad commercial communications satellites in various orbits, covering the frequency bands from VHF through EHF and beyond, funded and operated by the private sectors of numerous nations and consortia and will serve as the backbone for this military satellite communications architecture. Unimaginable amounts of information will flow over this global information system and will change the world's cultures, its caste system, its social order, its economy and the face of the information infrastructure will be changed in much the same way that the interstate highways once changed the face of the commercial infrastructure. As international and multinational partnerships are created and the language, culture, currency, etc. challenges are solved we will become a more understanding, holistic and better world. Hugh bandwidth arteries will be available over direct broadcast satellites that will enable high resolution imagery, digital TV and other high bandwidth data dissemination services to be delivered to the deployed warfighter.

What has emerged from the eye of the storm is the acute requirements for multilevel security, trusted systems, computer assurance and data integrity. The requirement, actually an essentially, of making available all possible information to the operational commander is universally accepted. As this information is maintained at multiple security levels, mandatory access control and encryption are required to protect this information, particularly as Coalition Warfare becomes a defacto standard operating procedure.

Mandatory access control mediates access to information based on its sensitivity and the clearance of the user trying to access it, provides a means of controlling access to information based on the sensitivity of the information as represented by labels of operating systems objects, i.e. files, devices, areas of storage, etc., and on the formal authorization or clearances of the user accessing the data. Mandatory access control and labeling are the key features of multilevel security systems and are the quintessence for this global information system. The requirement for trusted systems is not unique to the military. The best use of trusted systems technology is not to protect military secrets, but to promote commerce. Industry must accept the face that the company that can not protect their business data can not protect their business. All of the alpha-numeric categories of trust are of little concern to industry, that is more concerned with the protection provided than the pedigree of the security system. It does us little good to win a war and then lose our way of life.

This satellite communications architecture and infrastructure must be able to support, without restrictions, global joint and combined planning, simulation and modeling, rehearsal, event execution and post strike evaluation, including battle damage assessment.

4.3.4 Conclusions

Future multimedia communications capability will provide personal communications to any point on the globe, and very high data rate capability among virtually every populated area. These universal capabilities, whose transmission medium and routing will be transparent to the customers, will be available commercially and will provide reliability, flexibility, capacity, security and quality of service. The rate of technology changes will make it difficult to match these capabilities with any government-owned systems. The international nature of many of the providers of these services will blur the "source" of the capabilities (US-owned, allied, etc.). Connections to other information systems may be more limiting than the communications systems themselves, and access to spectrum or transit may be more difficult challenges than technology. There will be a rapid expansion in available bandwidth. Advances in microprocessors and antenna technologies could enable greater bandwidth and more reliable communications for the tactical, mobile users.

4.3.5 Recommendations

1. Craft a global terrestrial and satellite communications architecture whose infrastructure would be built upon existing and planned DoD and commercial capabilities.

2. That this resulting architecture be distributed, flexible, scaleable, seamless, fault-tolerant, reconfigurable, transparent to the users and include communication satellites in different orbits, in different frequency bands interconnected by cross links.

3. That DoD users that can reside on fiber optic arteries should be required to do so, and the warfighters given priority for satellite communications bandwidth for mobile, tactical users.

4. That veritable unique military survivable and enduring satellite communications requirements be identified and the resulting satellite designs be based on projected technologies.

4.4 Global Positioning, Time Transfer and Mapping

Ivan Getting, John Darrah

4.1.1 The Role of the Air Force in the Development of Space Based World-Wide Navigation

The GPS is the current (1995) space-based navigation system of the DoD.[1] The Air Force is responsible for the GPS Program Office (JPO) whose assigned responsibilities include the development and acquisition of the space segment, the ground control segment, and common military user equipment (UE). Each service (and platform development and acquisition Program Office) is separately responsible for UE imbedded in platforms (aircraft, vehicles, ships) or in weapons and missiles. The Air Force Space Command is charged with the operation of the GPS system. Since the GPS also serves as a "time-transfer system," furnishing accurate Universal Time Coordinated (UTC) world-wide, it coordinates UTC-GPS system time with International time (GMT) through the Naval Observatory. The Air Force Space Command integrates its global positioning with the Defense Mapping Agency (DMA) which is responsible for military mapping and geodesy - and the GPS uses DMA's established world grid WGS-84.

Geographic location and determination of local time go back to antiquity - usually based on the technology available for optical astronomical observation. All-weather positioning received a major boost in the past century by technological advances in radio (direction finding and "time signals").

About 50 years ago, stimulated by urgent need during World War II for more accurate all-weather position location and supported by improvements in electronic and radio technology (higher frequency, more bandwidth, time difference circuitry, etc.), a variety of ground-based Loran-type systems came into being. Performance was limited by radio propagation and/or masking. The invention of the transistor, followed by integrated chips, and reliable higher-power solid-state transmitters contributed to smaller, cheaper, and more reliable equipment. The invention of the maser, of atomic clocks, and of quartz-crystal controlled oscillators also contributed to advances in both position location and time determination and transfer. The major technological advances in support of position and time-transfer in the last 25 years was, of course, in space technology - the ability of putting satellites into orbit and accurately determining their orbits, "space qualified hardware," etc. - in all of which the Air Force played a leading role.

The first satellite navigation system was the Navy TRANSIT (operational in 197?). It was fielded to meet a specific Naval requirement of indexing the location of the SLBM submarine. It met the all-weather global accuracy requirement. However, the service was intermittent, horizontal (lat/long) only, and subject to errors induced my user motion; and, as such, it was not suitable for use in aircraft or missiles. It did not provide accurate time transfers. Navigation depended on the availability of complementary equipment (dead-reckoning, inertial systems, gyrocompasses, etc.). Nevertheless, it found broad application in both Navy and civilian ships - domestic as well as foreign.

1. 1994 DoD-DOT Radionavigation Plan

The first satellite system approach for providing passive continuous all-weather navigation position in three dimensions for use on aircraft and other highly kinematic users was the 621B study supported by the Air Force (1963). Being passive, it could serve an unlimited number of users. Being passive, the user was not subject to detection or tracking (e.g., by a military enemy). The system provided 3-D positioning by determining the range to at least 3 satellites. The system employed the most modern signal processing (pulse-code modulation; band-width compression to extract accurate range from very weak signals and support anti-jam and security requirements). Yet the User Equipment (UE) had to be inexpensive and reliable. Hence, a fourth satellite was added to allow the use of inexpensive quartz reference clocks in the UE, corrected to the Navsat system time. Three-dimensional accuracies of 15m SEP and 20 nanoseconds accurate time corrections to the UE clock were predicted and demonstrated on ground tests. It took a third of a century (31 years) to bring such a system to operational status (1994) - why?

The long gestation time was mostly "political" and government hierarchical. The performance for military applications and the multitudinous civilian uses of the system were largely predicted in early application studies; but who was to bear the costs (in billions of dollars) and who would manage and control? The 621B concept was described to the Agnew Space Task Group in 1969.[2] It was specifically labeled as a "lighthouse system in the sky" - serving not only DoD, but all mankind. It was turned down by the STG in favor of "manned stations serviced by shuttles." Within a year, Dr. Lee Dubridge, science advisor to President Nixon, reviewed the possibility of setting up a Presidential Commission to hold hearings on navigation satellites to identify: the principal civilian users and their needs; the non-DoD interested agencies of government(FAA, Coast Guard, Maritime Commission, Geologic Survey, etc.); the DoD branches, etc. In addition, the Commission would recommend an appropriate management and fiscal plan. After suitable consideration, and based on his substantial experiences, Dubridge stated, "It is too hard to get there from here; get one military department which has the greatest use, has demonstrated qualified experience in the management of large and expensive systems and run with the ball - when the performance of the system has been demonstrated, then like with past radionavigation systems, the others will climb aboard." The Air Force Research and Development Command accepted the challenge and with the support of civilians in DDR&E ended up managing (and funding) a Joint Program Office (July 1993), and the NAVSAT 621B program was renamed the NAVSTAR- GLOBAL POSITIONING SYSTEM or GPS.

The space segment of the GPS system consists of 24 satellites. With the launch of the 24th Block II satellite in March 1994, the GPS Navigation System was declared operational. (See Appendix A for a technical description.)

In the meantime, the war against Iraq (Desert Storm, 1991-1992) demonstrated without doubt that the GPS was a major "force multiplier" for all U.S. military services. This was soon followed by realization of its uses in many civilian and scientific applications.

2. The Space Task Group (STG) was established on 13 February 1969 by President Nixon to provide a post-Apollo space plan for the Nation.

4.4.2 The Responsibilities of Civil and Military Authorities in a World - Wide Satellite Navigation System

"The National Defense Authorization Act for Fiscal Year 1994 (Public Law 103-160) mandated an independent study, funded by the Department of Defense, on the future management and funding of the Global Positioning System (GPS) program."[3]

"Describing the need for this study, the Senate Armed Services Committee said: 'It is clear that GPS offers the potential to revolutionize the movement of goods and people the world over. Civil and commercial exploitation of GPS could soon dwarf that of the Department of Defense and lead to large productivity gains and increased safety in all transportation sectors' ".[4]

The independent study chartered by Congress stressed "the future management and funding" and recommended technical improvements. These recommended improvements addressed the current GPS-NAVSTAR system - and these are covered in Section III of this report. The principal management recommendations addressed civilian vs. military issues, U.S. vs. international issues, and U.S. national security. "no alternative governance and management arrangement emerged as fundamentally superior to the current arrangement at this time."[5] (Radio navigation coordination between DoD and DoT with DoD funding and operating the GPS.) Unfortunately, the "cat is out of the bag" [or genie is out of the bottle] - and mutually contradictory ongoing programs exist. For the future, the study recommended:[6]

> *The panel recommends that the President promulgate an executive order to set forth a national strategy and guidelines for GPS, establish a GPS Executive Board, reassert the policy of the United States to provide the civil GPS signal free of direct user charges world-wide, and announce that Selective Availability will be turned to zero immediately and deactivated after three years.*

Governance and policy leadership of GPS need a broader base and perspective. To achieve the national goals for GPS, the current governance and policy-making arrangement must be strengthened. *Therefore, the GPS Executive Board should be created as soon as practicable.*

> *The board, to be co-chaired by high-level designees of the secretaries of defense and transportation, should be responsible for governance oversight, highest level policy setting and policy guidance, and over all coordination for the entire GPS program, including augmentations.*

> *The board's membership should extend beyond DoD and DoT to the Departments of Commerce, Interior, and State, so as to be more inclusive and representative of the broad spectrum of the domestic and worldwide GPS user.*

> *The board should be directed to prepare and annual report for the President who, in turn, should forward it to the Congress.*

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3. "The Global Positioning System, Charting the Future", May, 1995, page vi
4. Ibid., p. vi
5. Ibid., p. 15
6. Ibid., p. 16-17

The board also should be responsible for formulating a comprehensive strategy to increase international acceptance and use of GPS that reassures foreign users of the reliability and consistency of the United States as a provider.

The board should ensure that DoD's and the Air Force's requirements processes effectively accommodate military and civilian GPS requirements and that appropriate means are established to fund non-military requirements.

The board, acting through its co-chairs, should be responsible for resolving disputes arising over GPS program management, operations, and funding.

The NAPA panel also recommends that:

DoD retain responsibility for operation and maintenance of the basic GPS, and the Air Force continue to act as executive agents; DoD also should continue to be responsible for international military cooperative arrangements.

DOT should be strengthened and become a more assertive executive agent for all US civil systems, oversee US participation in international organizations and GPS-related systems, and make arrangements with DoD to satisfy civil requirements for positioning and navigation using the civil SPS signal.

The executive order recommended above should provide a stronger charter for DOT's role, but effective leadership will be needed to carry it out. In this role, DOT should:

Coordinate civil agency requirements for and use of GPS and actively represent the civilian GPS community (including private and commercial interests, both domestic and international).

Institutionalize its consolidated requirements identification process for all civil requirements for GPS and work with DoD to formalize the mechanisms for incorporating them, where appropriate, into the current military operational requirements process for GPS.

Work with DoD to better coordinate military and civilian research and development efforts.

Cooperate with the Air Force to monitor and report on the integrity of the civil GPS signal.

Regarding use of the private sector for GPS differential services, the panel recommends:

As a general policy, the federal government should make use of the private sector for GPS augmentations beyond those specifically designed or required for public safety and national security.

The SAB-Space Applications panel differs from the report in regard to Selective Availability. While SA should be turned to zero availability - primarily to placate domestic and international civil and commercial entities, the panel disagrees that it should be "deactivated after three years." Some form of SA capability should be available to the NCA.

Technical improvements in UE, compatible with the existing space segments, can be introduced on an evolutionary schedule. However, physical changes in the space segment are necessarily gaited by the replacement schedules of the satellites. It is, therefore, necessary to discuss the future of the GPS in the near term, roughly 25 years (1995-2020 covering the current Block IIR and the Block IIF scheduled for proposal release in August 1995 with first launch in about 2005). Presumably some modifications in system operation can be introduced in Block IIF if provisions are made for switching and computer flexibility (software changes). Near term improvements are covered in Section 4.4.3

Major technological changes in the space segment of GPS Block IIF must wait to about 2020 (2025 - far term). Circumstances can arise which might require a "new start" of a purely military system or of special "add-on" satellites even in the near term. Both the "far-term" and "add-on" require pursuing new technology on a continuing technology program which is adequately funded.

There is general agreement that the GPS system will have enormous civilian economic impact - both directly and indirectly through savings on the provided services. On the other hand, national security is a key element for both U.S. survival as well as for economic well-being. Even a cursory review of history leaves little hope for a future free of strife and wars. To the long list of historic causes of strife, terrorism, and wars (nationalism, religion, economics, irrational ambition and leadership) we now must add overpopulation, depletion of natural resources, and environmental issues. To exacerbate these problems, many user technologies have recently been added of mass destruction (nuclear, biological, chemical). Recognizing these technological facts, the GPS subpanel of Space Applications Panel of the New World VISTAS endorses the footnote 3 on page 5 of the "GPS - Charting the Future" report, "As with all other federally-funded navigation systems, the ultimate decision-making authority over GPS operations, in peacetime and in wartime, is the National Command Authority (NCA), consisting of the President or, with the approval of the President, the secretary of defense."

Nevertheless, technical questions persist. Can the U. S. deny the enemy's use of GPS against us without doing harm to our own forces, or to friendly users of GPS (civilian and military)? Can we protect U.S. military use of GPS against international and/or non-international interference from both friendly emitters and enemy jamming equipment? Can technology produce answers?

4.4.3 Issues - The Importance of Assuring Frequency Allocation and Code Structures for the Future of Civil, Military, and Commercial Navigation

There have been radical changes in the use of the radio frequency spectrum since GPS was initially designed in the early 1970's. Lack of a national policy for promoting the international protection of the GPS frequencies from interference threatens the long term viability of GPS as the key component of a worldwide navigation satellite system for civil and military users.

GPS occupies two Radionavigation Satellite bands designated for Space-to-Earth broadcasts by satellites. One band, extending from 1559 MHz to 1610 MHz, contains the GPS L1 signal centered at 1575.42 MHz (see Appendix A for a discussion of the GPS navigation signal structure).

This band is also allocated for Aeronautical Radionavigation, which includes safety of life systems. The second, extending from 1215 MHz to 1260 MHz, contains the GPS L2 signal centered at 1227.60 MHz. This band is shared with an allocation for radiolocation, which includes air traffic control radar.

GPS was joined in the early 1980's by the Russian GLONASS. Providers of GPS augmentation signals have hitherto been using other frequency bands (e.g., Inmarsat II, John Chance & Associates), but are now implementing or planning services in the radionavigation satellite bands occupied by GPS (e.g., FAA's Wide Area Augmentation System, Japan's MTSAT). Meanwhile, there is increasing use of the spectrum above and below the radionavigation satellite band. This trend may result in interference to GPS or other systems through out-of-band emissions, which are not as easily enforceable as in-band sources of interference. To a large extent, neither international regulation nor U.S. policy has paid adequate attention to the spectrum needs of GPS civil or military users. The accompanying figures illustrate the increasingly crowded spectrum near L1. Some systems depicted have been announced, but are not presently funded.

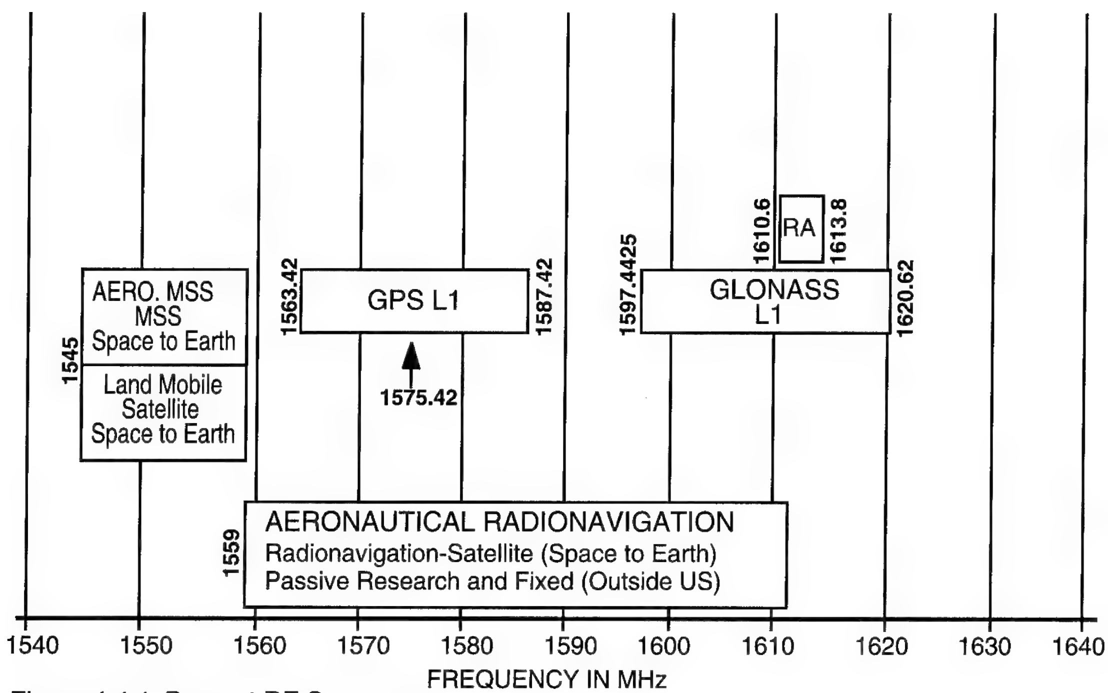

Figure 4.4.1. Present RF Spectrum

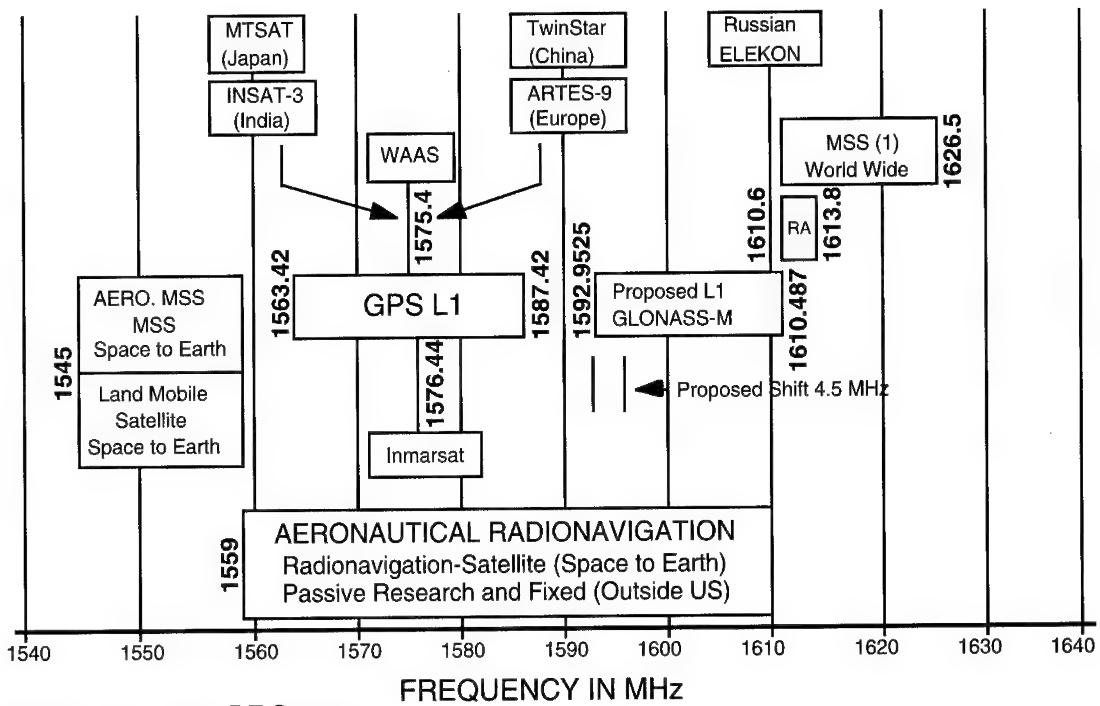

Figure 4.4.2. 2005 RF Spectrum

Use of the radio spectrum, when that use extends beyond national boundaries, is administered by the International Telecommunications Union (ITU), an agency of the United Nations. The GPS L1 and L2 frequencies are registered with the ITU as primary allocations and L1 as a safety of life service. But under ITU rules, protection of the allocation applies only within U.S. boundaries and within other nations which agree to protect GPS. The radionavigation satellite band is also explicitly for space-to-earth propagation, not space-to-space. Note that this means:

- There are no assurances that competing systems cannot operate on or near the GPS frequencies (i.e., neither DoD nor the U.S. "own" L1 or L2)
- There are no assurances of non-interference to GPS outside U.S. boundaries, and
- There is no protection whatsoever for any spaceborne GPS user

Interference to GPS occurs when the strength of the interfering signal degrades or overwhelms the GPS signal within the GPS receiver. Interference is caused by insufficient margins of relative power, frequency, or code separation between GPS and the interfering signal. The power issue is familiar to many: A very strong or very near transmitter can overwhelm a receiver, even if the transmitter is operating within specifications. In some cases, components in the receiver itself generate intermodulation products within the receiver passband from a signal source quite far from GPS in frequency.

The frequency issue is slightly more complex: The interfering signal may be on or near the GPS center frequency and hence within the receiver's passband. The signal may be in nearby

parts of the spectrum outside the passband, but may have "spillover" that falls within the receiver passband. For example, certain types of handheld Mobile Satellite Service transceivers in the band adjacent to GPS may still interfere, if the transceiver is physically close enough to the GPS receiver. Finally, the signal may generate harmonics which fall within the receiver passband. UHF television channel 23 is frequently cited as an example of the latter; the channel 23 video carrier operates at 525.25 MHz, the third harmonic of which is 1575.75 MHz. However, tests to date have not established whether the sporadic cases of interference are due to harmonics of the TV transmitter or intermodulation products generated by the GPS receiver.

Finally, the signal modulation determines the level of interference. GPS uses spread spectrum and code division multiple access (CDMA). The spread spectrum technique mitigates the effects of narrowband and continuous wave (CW) interference. The CDMA technique allows multiple transmitters to operate on the same frequency with minimal interference by assigning each transmitter a separate code chosen from a "family". The GPS C/A codes, used by the civil Standard Positioning Service (SPS), are from one family of Gold codes. For maximum compatibility with GPS, services on the GPS frequency should use members of the same family.

Current international procedures fail GPS in four ways. First, the Department of Defense carries no weight in the international bodies. Those bodies focus solely on the protection of allocations with current or near-term utility to the general international community (e.g., the civil SPS signal). Second, they treat GPS as one more system that is privately owned or owned by a single nation. This treatment ignores its potential as a worldwide international system. Third, there is no procedure for coordinating the common use of compatible codes to mitigate interference. And finally, the procedures fail to provide guidelines for protection of the growing spaceborne use of GPS.

Given the vanishing spectrum available for use and the growing number of potential new systems, strong national leadership is needed in developing procedures for the protection of the U.S. investment in GPS.

4.4.4 Issue - Wartime Use of GPS

Closely related to the previous issue of frequency allocation and code structure are:

1) Can the U.S. deny the enemy's use of GPS against us without doing harm to our forces as well as to friendly users of GPS (civilian and military); and

2) Can we protect U.S. military use of GPS against interference by enemy jamming equipment?

In regard to item (1), the problem of denying the enemy's use of GPS is somewhat simplified if SA does not exist - all that is currently required is to locally jam the enemy's C/A UE since the P(Y) code and associated frequencies are not available to the enemy. Various schemes for such jamming are available; but the Air Force should continue the development, test and acquisition of such equipment. Some peripheral civilian jamming may result.

In regard to item (2), the P(Y) should be exploited by the military for wartime use, e.g. acquisition in the P(Y) code by all moving platforms prior to take-off (fighters from airfields or carriers; cruise missiles from launch vehicles; bombs and other missiles from aircraft); electronic distribution of crypto keys should be implemented at earliest possible date, etc. Additional

improvements suggested in Task 2:" Recommendations That Enhance GPS Performance for Military Users:[7]

The development of receivers that can rapidly lock onto the Y-coded signals in the absence of the C/A code should be completed. The deployment of direct Y-code receivers should be given high priority by the DoD.

Nulling antennas and antenna electronics should be employed whenever feasible and cost effective. Research and development focused on reducing the size and cost of this hardware should actively be supported.

The development of low-cost, solid-state, tightly-coupled integrated inertial navigation system/GPS receivers to improve immunity to jamming and spoofing should be accelerated.

The development and operational use of GPS receivers with improved integration of signal processing and navigation functions for enhanced performance in jamming and spoofing should be accelerated.

Military receivers should be developed that compensate for ionospheric errors when L_1 is jammed, by improved software modeling and use of local-area ionospheric corrections.

4.4.5 Issue - Continuing Improvements of the GPS System

The Congressionally chartered GPS study also recommended continuing improvements in the GPS leading to horizontal accuracies of a stand-alone GPS accuracy of 6 meters. Such improvements would reduce the use of differential GPS to special localized uses: Category III precision landing, maritime harbor pilotage, etc. Their recommendations are here, quoted verbatim - and this panel believes the Air Force should review those recommendations:[8]

Additional GPS monitoring stations should be added to the existing operational control segment. Comparison studies between cost and location should be completed to determine if Defense Mapping Agency or Air Force sites should be used.

The operational control segment Kalman Filter should be improved to solve for all GPS satellites clock and ephemeris errors simultaneously through the elimination of partitioning, and the inclusion of more accurate dynamic models. These changes should be implemented in the 1995 OCS upgrade request for proposal.

Procurements for the replacement of the monitor station receivers, computers and software should be carefully coordinated. The new receivers should be capable of tracking all satellites in view and providing C/A code, Y-code, and L_1, and L_2 carrier observables to the OCS. Upgradability to track a new L_1 signal also should be considered. OCS software also should be made capable of processing this data.

Firm plans should be made to ensure the continuous availability of a master control station.

7. Ibid., p. 24
8. Ibid., p. 24-25

A simulator for the space and ground segment should be provided as soon as possible to test software and train personnel.

The operational control segment software should be updated using modern software engineering methods in order to permit easy and cost-effective updating of the system and to enhance system integrity. This should be specified in the 1995 OCS upgrade request for proposal.

The planned Block IIR operation should be reexamined and compared to the accuracy advantages gained by incorporating inter-satellite ranging data in the ground-based Kalman Filter and uploading data at some optimal time interval, such as every hour, to all GPS satellites.

Block IIR satellite communication crosslinks should be used to the extent possible with the existing crosslink data rate to support on-board satellite health monitoring for improved reliability and availability and in order to permit a more rapid response time by the operational control segment.

The Block IIR inter-satellite communication crosslinks should be used to relay integrity information determined through ground-based monitoring.

The DoD's most frequent satellite navigation correction update strategy should be fully implemented as soon as possible following the successful test demonstration of its effectiveness. In addition, the current security classification policy should be examined to determine the feasibility of relaxing the 48-hour embargo on the clock and ephemeris parameters to civilian users.

4.4.6 Issue - Long-Time Evolution of Global Positioning and Time Transfer

As stated on page 3, major changes in the space segment may not be economically feasible until about 2020. This does not preclude adding complimentary satellites to enhance the role of space for global positioning and time transfer. For example, it is possible to add "special satellites" even into the current constellation which might radiate substantially higher power in support of the P(Y) code and which might illuminate the entire earth's disc or alternatively, using higher gain antennae to illuminate just the combat area, etc. There is room for analysis on other orbital options.

With time, the determination of satellite orbits will improve, atomic clock technology (maybe using masers) will improve, compact accurate INS will become available, better "GPS"-"INS" integration and receiver tracking of both range and range-rate (Doppler) will result. Such expected improvements when integrated in UE, together with more accurate data on the troposphere[9], lead the panel to conclude that in the 2025 period the horizontal accuracy of the PPS can be brought down to 30 centimeters and time transfer to 1 nanosecond.

9. John McLucas (703-765-9310), letter to Space News dated May 11, 1995 titled "GPS/MET Lives!"

4.4.7 Conclusions and Recommendations for the Future System

The fundamental aspects of the design of the current GPS system were frozen in the 70's. There are many technical improvements which can provide the international, as well as the US, civil and national security needs.

We believe that there are new system designs that can significantly improve the warfighting capabilities (accuracy, security, anti-jam, anti-spoof) for the military users and the abilities to deny capabilities to international terrorists, rogue nations and those in active conflict with the U.S. and its Allies. These capabilities need not interfere with international peaceful civil and commercial needs for very precise location, time transfer and mapping needs.

The technology for incorporating many of these improved capabilities is currently available. The Air Force should incorporate changes as soon as they deem it practical in the satellite procurement. The new systems can be backward compatible for the civil users. We recommend that system design trade studies begin immediately to support future decision making. Laboratory and on orbit demonstration can be used to further reduce risks and increase confidence that there is a win-win system that is feasible and affordable.

One of the most important steps which needs to be taken is to protect the PPS frequencies. This is a complex national and international process which was developed prior to mobile and satellite transmitters. The result is an arrangement that takes a very knowledgeable staff and interagency cooperation to protect U.S. futures.

There are several system designs which could compete for the best solution to future civil and military needs. A strawman set of features which might characterize a new system based on the current system are:

Two frequencies for civil as well as military users to give them ionospheric propagation corrections.

Real time tropospheric moisture propagation corrections.

A combination of bandwidth, power, and orbital parameters that increase by a large factor (perhaps 1000) the signal that military receivers would have available.

Fast electronic distribution of cryptographic keys and wide availability of different keys would enhance security and flexibility.

Flexible signal generation that permits future satellite improvements via reprogrammable hardware and software.

4.5 Space Control

George A. Paulikas, Ivan. Bekey, J.G. Gee

4.5.0 Introduction

The totality of US spacecraft in orbit twenty to thirty years from now, military and commercial, together with their ground-based control nodes and launch sites will form a high value element of the national military capability. During the time period of interest, there will also be constellations of spacecraft operated by other nations and international consortia. Adding to the complexity of the situation expected to exist 20-30 years from now, is the likely presence of several, if not many, larger, manned space stations and space power stations. It may be in the national interest of the US to develop and deploy capabilities to disrupt, degrade or even destroy the space assets of adversaries with great precision and discrimination while also having the capability to protect U. S. national security and commercial assets by passive and active means.

4.5.1 Likely Threats

4.5.1.1 Jamming

Introduction

Electronic warfare jamming represents one potential method to be employed against space assets because the required technology is available worldwide. The development of jammers targeted against specific systems would depend on the importance the U.S. attached to attacking the system and how vulnerable we perceived the system to be to this form of attack. Jamming could be used to perform uplink and downlink jamming. These topics will be discussed below.

Uplink Jamming

In an uplink jamming role, the jammer would attempt to inject brute force noise or other selected jamming waveforms into the satellite receivers or transponders in orbit. The uplink signal to be jammed could be vehicle commands or the forward communications path for a satellite communications system. Interference with the vehicle command uplink might prevent the vehicle from performing its intended mission. Jamming against a communications signal would be intended to prevent the dissemination of the signal's information content to the intended recipients. Either option is attractive because interference with the command link can potentially deny the entire mission function of the system while interfering with a communications uplink can degrade or deny communications to many users simultaneously while not requiring the jammer to be located near the intended victims.

Jamming the command uplink of military satellites would require the jammer to be within the command uplink reception main beam because power entering through the sidelobes would not be sufficient. The use of high uplink frequencies and highly directional uplink reception antennas would result in small reception beam footprints and thus complicate the placement of a high powered jamming source.

Jamming the forward communications path of a satellite communications system is another potential application of uplink jamming. The potential uplink sources can be dispersed over a wide geographic area resulting in a large number of potential jamming locations. Satellites

using high frequency (SHF or EHF) uplinks have anti-jamming capability because the reception footprints are small, the wider available bandwidth complicates the jammer's mission, and nulling antennas can be used to further combat jamming attempts. Satellites operating in the UHF spectrum are much more vulnerable to uplink jamming because of their large reception footprints, limited bandwidth, and inability to use antenna nulling due to the prohibitive physical size of the required apertures.

Uplink Jamming Systems

An airborne system has no significant range advantage over a ground based jammer when targeted against space systems and would require an extremely complex system with high gain, steerable antennas. High power would be difficult to achieve because of the constraints imposed by the aircraft basing. A spaceborne jammer would have a significant range advantage over a ground based jammer but would suffer from extreme power constraints. These power constraints would require the jammer to stay within close proximity to the intended target which implies a sophisticated space launch, tracking, and control capability. For these reasons, airborne and spaceborne uplink jammers are considered unlikely candidates for development. Potential uplink jammers will likely be mounted on fixed, transportable, or mobile terrestrial systems.

A fixed ground based jammer would be effective because of its greater power but it would be technologically complex, expensive, vulnerable and would require a highly trained crew of technicians to maintain and operate. Such a jamming station would be deployed in very limited numbers. The lack of mobility of a ground fixed station results in the least tactical flexibility and the system's location can be determined rapidly and accurately once it is employed operationally (or during testing.) Thus this system would be most vulnerable to direct physical attack.

A transportable jamming station is defined as a single, high powered jammer which can be mounted on a large vessel or can consist of several trucks. The station is considered to be technologically complex and expensive and to require a large amount of logistical support. The setup/tear down time is postulated to be on the order of several hours. A trained crew of technicians is also required to maintain and operate the system. This type of jammer would most likely be deployed in limited numbers. The transportable nature of the system would provide increased operational flexibility and survivability at the expense of reduced transmitted power.

A mobile jamming station is defined as a high powered jammer which can be mounted on a small vessel such as a fast frigate or can consist of two to four trucks. This type of jammer is considered to be the least complex and expensive of the three classes. Potentially we could deploy a large number of mobile jammers to provide a distributed jamming threat rather than a single point, high powered jammer. The setup/tear down time is postulated to be less than several hours. Since mobile stations are prime power limited the jammer output power would be the smallest of the three types. However, this system would provide maximum tactical flexibility and maximum survivability to direct physical attack.

Downlink Jamming

Downlink jamming is sometimes the only way to effectively jam a space system. In the downlink jamming role, the jammer would attempt to inject brute force or other selected jamming waveforms into the satellite user receivers located on Earth. Effective jamming of the

ground receivers is dependent on power, time, and geometry. The jamming signal must be directed toward the target receivers with sufficient strength and at the proper time to block or confuse reception of the intended message. The jammer must be within line of sight of the target receivers. Downlink jamming might be employed against any space systems supporting force enhancement functions such as navigation, communication, environmental sensing, and reconnaissance/ surveillance. Generally, multiple intended receivers must be targeted. These receivers would typically be located in areas of regional conflict or crisis. Thus jammer deployment would be simpler than uplink jamming targeted against command transmitters located in other countries.

Downlink Jamming Systems

Airborne systems make the most sense for potential downlink jammers because they can provide simultaneous line of sight to a large number of potential earth based receivers. Space-borne jammers in low earth orbit could potentially see many more downlink receivers than an airborne system at a given point in time but they would require higher power for the same effectiveness as an airborne platform due to their greater range from the intended targets and a single platform would have only several minutes visibility to any particular operating region, necessitating multiple platforms for effective regional jamming. Thus space based downlink jammers are no an attractive option due to the requirement to operate at appropriately high altitudes with a formidable aperture. Another viable alternative is a low powered, expendable jammer that could be placed in limited numbers to accomplish specific mission objectives as described below.

The technological issues involved in building a credible brute force jammer against satellite downlinks are relatively simple. It would be feasible given sufficient time and a number of suitable fixed or rotary wing aircraft, to configure a challenging noise jamming capability. The challenging part of developing this threat capability is commitment of the airborne platforms and integration of these jamming systems into overall air operations. Although these systems would be power limited, their enormous range advantage over the satellite transmitter makes them viable concepts. The current and near term trend is the acquisition of small/medium, dedicated fixed and rotary wing aircraft to perform conventional airborne jamming missions. Unmanned air vehicles are being increasingly used in this role. These same type of systems could be modified for use in the downlink jamming role.

4.5.1.2 Kinetic Energy and Directed Energy Systems

Introduction

A variety of kinetic energy and directed energy systems could be used to threaten space assets. These threats are all technically more challenging and expensive than electronic warfare jamming, information warfare, or ground station attack. Amplifying material on these potential systems are provided below.

Kinetic Energy Weapons

Kinetic energy weapons employ high speed projectiles to damage or destroy targets through the mechanism of kinetic energy transfer without the use of any type of explosive warhead. A variety of mechanisms can be used to deploy kinetic energy weapons against space systems.

Examples might include satellites maneuvered to act as weapons (co-orbital interceptors or space mines,) missiles launched from aircraft or other satellites, and ground based missiles used in direct ascent attacks. A key requirement for these type weapons is the ability to get the weapon in close proximity to the target. Such a weapon would require surveillance and identification capability to acquire and track the targets with sufficient accuracy and timeliness, and some maneuvering capability to perform the engagement end game. Direct ascent missiles are the most likely delivery options for regional type adversaries. Space or aircraft based missile systems would have some advantages over ground based systems (reduced engagement timelines, potential covert employment) but their development would imply considerably increased system complexity and system integration risk. The constraining factor in developing a comprehensive low altitude kinetic energy capability is the required infrastructure and the development of the kill vehicle.

Directed Energy Weapons

Directed energy systems conceivable for attacking space systems include lasers and radio frequency weapons. Two types of laser ASAT systems could be developed An out-of-band system is designed to inflict physical damage on a target satellite due to the exposure to high powered laser radiation. An in-band system is intended to spoof, jam, or damage sensors carried on the satellite whose operating frequencies include the laser weapon's frequency. An in-band system can be effective at a much lower power level than an out-of-band system but it requires the ability to ensure the laser can illuminate the target sensors. Lasers could potentially be ground based or housed in airborne or spaceborne platforms.

Out-of-band systems in particular are technologically complex and expensive and would require lengthy and expensive development efforts. In-band systems might be a more viable option because of the lower level of technology and expense required. However, an in-band system is not a trivial development because of the requirement to accurately point and maintain the beam on the targeted space based sensors. This aspect of the problem is particularly challenging for rapidly moving low earth orbiting targets. Targeting electro-optical missile launch detection sensors based on geosynchronous platforms might simplify the target acquisition and pointing problems.

Any laser ASAT system developed would probably be ground based. An aircraft system could fly above the weather that can prevent propagation of laser radiation from the ground to space, it would suffer less from atmospheric effects that attenuate or distort the laser beam, it would provide more tactical flexibility, and it would have increased survivability. However, such a system would have reduced power levels (and no appreciable range advantage over ground based systems) and have considerably more difficulty in acquiring the target and pointing and maintaining the weapon beam because of the rapidly moving platform. A space based system could operate at much lower power levels due to decreased range to the targets and would eliminate any atmospheric impacts but would require a major, expensive, and risky development.

Large amounts of radio frequency energy directed at a target satellite can produce damage, upsets, and disturbances. The required amounts of energy are much greater than would be required for satellite communications or jamming. A ground based system would require a large power source and a large antenna. These requirements in turn would require a fixed site that

could easily be located and thus subject to physical attack. The requirement for high powers and large antennas preclude air based options because the required powers are not significantly less than ground based weapons. A spaceborne or missile borne weapon could get much closer to a target and so operate at considerably reduced power levels but the development of such a capability by any potential adversary would require considerable technical expertise, development, and expense.

4.5.1.3 Threats to Ground Elements

Introduction

Perhaps the simplest method to attack space elements are attacks aimed at the ground elements required to support all space operations. Elaborate weapons and space systems capability are not required. The locations and functions of a number of critical space support facilities are widely known. Information warfare options directed against these space support facilities were addressed above. This section only considers physical threats to the various space support facilities.

Launch Complexes

The locations of launch complexes are widely known. Preventing the replenishment or augmentation of space capabilities can be accomplished by an effective physical attack against these limited number of complexes. Our with strategic power projection capability could target the complexes with ground or sea based ballistic missiles. Air assets could also be used. We could use special operations forces and conventional means although this approach would presumably be more difficult. It is unlikely that potential adversaries would have the ability to reconstitute critical launch facilities if they were attacked and destroyed.

Command and Control Facilities

Targeting launch facilities would be perhaps not be an effective strategy if the adversary's launch systems were not intended to provide rapid combat support. The most effective strategy to neutralize a large number of on orbit space assets is to target their command and control sites. If the location of these sites were known, they could be subject to the same physical threats as the launch complexes. An effective countermeasure to this type of attack would be the use of mobile ground stations to perform the command and control function.

Data Processing Centers

Military space support systems that provide data to central sites for processing and subsequent dissemination to users are vulnerable to attacks on such sites. The same threats apply as those listed above. Dissemination directly to the end users would thwart this approach but such a countermeasure impacts the system architecture and requires the development of equipment that can be deployed to the user locations and provide adequate functional capability. If multiple users desire to directly control the satellite's data collection and reporting capabilities the complications increase.

4.5.2 Space Traffic Control

Space traffic will increase dramatically in the next decades, principally due to the proliferation of LEO satellite systems, both commercial and military. There will also exist an

international space station, and one or more commercial industrial parks. In addition, there will exist naturally occurring and man-made debris objects in orbit. This section examines what must be done to ensure an ability to operate effectively in space in this environment.

Current traffic to space amounts to somewhat less than one million pounds annually, represented by some 50 spacecraft launches worldwide. The future will be very different, due to the onset of small, proliferated, mainly low altitude satellites. Foremost among these will be commercial communications systems such as Iridium (66 spacecraft) and Teledesic (850 spacecraft), but will also increasingly include military systems such as Brilliant Eyes (30 spacecraft). These will be replaced periodically with more advanced systems, and the old commercial constellations likely be sold to second tier users. Thus, in contrast to today, in 20-30 years there will likely be hundreds to thousands of small-to-medium-sized satellites in orbit. In addition, very large and probably manned systems will exist, such as an International Space Station and one or more Industrial Space Parks. As space operations mature and servicing/ upgrading of reusable space systems becomes routine, there will be a need to control approach and departure corridors, at least around the large space facilities and in the more heavily populated orbits, in a way akin to air traffic control today.

In addition to active spacecraft, micrometeorites and an extensive population of man-made orbital debris population exists, principally in low altitude orbits. The most troublesome of these is the orbital debris, since it is easy to shield spacecraft against micrometeorites. There are today about 150,000 debris objects in orbit in the size range of 1-10 cm diameter, which represents the greatest thread to damage to spacecraft due to hypervelocity impact. Though the frequency of impact of smaller particles is larger, they are relatively inexpensive and easy to protect against. Impact with debris objects much larger than 10 cm is probably not survivable, but the number of such objects in orbit is fairly small. Therefore a few high value spacecraft can be given warning by a surveillance network to make minor maneuvers so as to cause a miss of a few hundred feet. But the 1-10 cm size debris, which are too numerous to maneuver against and too expensive to protect against, will require some action.

Most orbital debris is so long-lived that even if near-perfect mitigation techniques were implemented, the existing debris population might not be reduced significantly for decades. There are also controversial models of secondary collisions which could cause an exponential increase in the number of objects. It is possible to reduce or essentially eliminate much of the orbital debris threat. A moderately sized ground pulsed laser can be targeted against individual debris objects, causing a surface plasma blowoff. This blowoff creates an impulse which, if applied at the proper orbital location, can reduce the debris object's perigee and therefore its lifetime.

It is estimated that most debris objects between 0.5 and 10 cm. in size can be completely cleared from low altitude orbits in 4 years by only one laser site. The laser system requires a surveillance sensor system to detect the debris objects, track them, and point the laser at the objects. The accuracies required are demanding, but attainable. This kind of a laser debris-clearing system is being defined in a NASA study just getting underway, and could be a practical solution.

Though debris at GEO altitudes is less of a problem, it may grow to significance, particularly if very large communications spacecraft are fielded there. Ground-based lasers are not a practical

way to clearing such debris, though a space-based laser may be. However, for both low and high altitudes, passive sweeping using maneuverable spacecraft dragging large balls of Styrofoam or aerogel on a tether may also prove effective. Ultimately, these may have to be augmented by active spacecraft to capture and change the orbits of larger debris and the increasing number of dead satellites.

An active space surveillance system will be needed to control this environment. Such a system could well be an outgrowth of the current Spacetrack system, but may need sensitivity, coverage, and other augmentations. These augmentations could be spaceborne, and indeed could be dual functions of spacebased surveillance systems whose primary functions are aimed at airborne or surface targets.

In addition, the capability will have to be developed to communicate with all active spacecraft via standardized commands, much as is the practice for aircraft under positive control. Due to the proliferation of spacecraft owned and operated by other nations and by international consortia, this surveillance and command system may have to be internationally operated, or at least various national systems will have to be internetted. In essence, a space traffic control system will be needed, controlling traffic in and around high value spacecraft such as the Space Station, and in populated LEO and GEO orbits. A number of security issues will have to be faced if an effective space traffic control is to be adopted.

4.6 Force Projection from Space

Ivan Bekey

4.6.0 Introduction

The natural use of space is to move and deliver energy, not mass, due to the cost of getting mass out of the earth's gravity well into space. For this reason communications, observation, and other information applications of space have been the first to be widely exploited, and why these functions of space are currently the only ones used to support the warfighters. However, advances in technology expected to be available in the next two decades, in concert with greatly reduced cost of access to space expected to occur in the next decade, will also permit practical uses of space to include delivery of much larger amounts of energy, as well as small amounts of mass. This will therefore allow the use of space assets to project force against surface and airborne threat elements, as well as against space objects and ballistic missiles.

Satellites present a presence over battle areas that is difficult to deny, and do so repeatedly and frequently enough from LEO, or continuously from GEO, so that force application using them could have a marked strategic as well as tactical effectiveness on the conduct and outcome of conflicts. This force can be applied anywhere rapidly, with minimal risk to U.S. forces, and at all levels of conflict. It is equivalent to artillery and strike support with infinite range and moving at 25,000 mph., with the added advantage of enjoying complete surprise.

New technologies will allow delivery of very large amounts of precisely aimed and focused electromagnetic energy at microwave and millimeter wavelengths from electromagnetic weapons; as well as optical energy from lasers with much lower cost and greater number of shots than past designs. In addition, they will actually allow small but very effective amounts of mass to be delivered against surface and airborne targets precisely enough as to have locally devastating effects.

4.6.1 Delivery of Munitions from Spacecraft

Developments pioneered by the SDIO/BMDO in space based precision guided, small, lightweight hit-to-kill interceptors with large divert radius can be adapted for interdiction of surface or airborne targets. With application of a small deboost rocket, and inclusion of large l/d rods made of depleted uranium, these munitions are able to deorbit autonomously or on command, and guided via GPS to a precision strike at hypersonic velocities essentially anywhere on earth.

The extended rods of these munitions would be able to penetrate hundreds of feet into the earth to destroy hardened bunkers or other buried facilities. Used in the divert/homing mode, and fitted with multiple pellets, these weapons would be deadly against high value airborne targets as well, such as AWACS-type aircraft.

These weapons could be used sparingly, but with devastating accuracy and effect, and little collateral damage or exposure of friendly forces. This ability to call down and accurately deliver mass from orbit on surface or airborne targets with complete surprise amounts to munitions with ultimate stealth, for which there is little effective passive defense. Cost effectiveness compared to delivery of similar capability via artillery for from the air may show favorable

ratios when the entire cost of placing and supporting more conventional capabilities is taken into account.

4.6.2 Delivery of Electromagnetic Radiation from Space

The technology of high RF power and large antennas is about to greatly expand. This technology would enable very large diameter thin film antennas, or the formation of very large coherent essentially-filled arrays controlled by cheap, small super-processors. When combined with large sources of RF power, on or off-board, such spacecraft could project very narrow beams of extremely high power density long distances to space, airborne, or surface targets. Their availability and use would greatly overpower electronic equipment so as to either incapacitate them for extended periods or destroy their front ends. In addition, they could jam or spoof them, introduce network saturation, disruption, viruses, disinformation; or all of these effects.

Such spacecraft would constitute a quintessential electromagnetic warfare and information warfare capability, that could operate over battle or denial areas with impunity. In fact, the power densities available would be so large that the spacecraft could well be placed in GEO, so that one or at most a few of them would have the ability to operate continuously as a strategic or tactical weapon of great effect.

As an example consider an ability to generate as little as 100 kW of power, about what is used on the NASA Space Station. Thin-film membranes supported by inflatable structural elements or electrostatic forces are now being developed. These techniques lend themselves to formation of filled apertures perhaps in the high tens of meters diameter, with surface accuracies usable up to Ka band. These antennas would be an order of magnitude lighter and less costly than those with conventional deployable structural elements.

In addition, techniques now being developed at JPL will allow precision station keeping of separate elements of a phased array, with control to enable all elements to radiate or receive coherently. These techniques dispense with structural members altogether, creating a "virtual structure", which is the lightest of all. In essence, structural webs are replaced by information webs—a perfect application of the natural characteristics of space. With these techniques, it is planned to emplace elements that can be separated by tens or hundreds of kilometers. These would form thinned or sparse arrays, which have exquisitely fine resolution, comparable to that attainable in the optical regime, and could be useful for many intelligence applications.

However for power transmission it is necessary to have an essentially filled array, lest the power be placed into the sidelobes. For force projection beam applications the elements would be moved together, and stationkept such that the gaps between them are less than half the wavelength, which is quite feasible up to the high tens of gigahertz. The resulting array is filled, and its size is solely determined by the number of elements fielded. Array sizes of many hundreds or meters diameter or more will be feasible, limited mostly by the budget available. In this context, a small array can be fielded, and as more money is available, additional elements added. This creates an antenna for a weapon that has incrementally increasing performance as funds are available.

With either type of large antenna, the ability to project RF power with such a system would be awesome. Consider an antenna of 100 meters (330 ft) diameter. It would have a gain

of almost 80 dB at X band, and if a power source of 100 kilowatts were used, the effective radiated power (ERP) of the system would be about 130 dB. This is 10 million megawatts! If the system were deployed in GEO, its footprint on a battlefield would be 6 miles diameter. The power density over this area would be 10 w/sq. m, and the field strength about 1 volt/meter. These power densities and field strengths are about 13 orders or magnitude above the sensitivity of typical communications receivers, and about 6 orders of magnitude greater than that of typical radar receivers and optical or IR sensors. They are far above the damage threshold for these receivers.

Thus in use, all radar receivers in a 6 mile area would be totally blanked out, and all unprotected communications sets either burned out or damaged. Larger arrays of film antennas or stationkept arrays would reduce the footprint. 1,000 meter antennas are entirely possible, which would have a footprint of about 1 mile from GEO. These systems could have a multiplicity of beams, all electronically steerable and independent. Their use in the field would constitute a "jam-on-demand" capability, if not a "burnout enemy sensors on demand" capability which could be used with surgical precision, in real time, and all the time. The small footprint and sidelobe control would allow them to be used with surgical precision, and with little collateral effect on friendly sensors or forces.

In addition, the awesome power densities would allow certain injection of signals into even heavily shielded communications networks, which would allow information warfare to be waged at will. Network viruses, disinformation, memory erasures, false signals, and other forms of information warfare could be injected where desired. The high energy density of the signals would assure their penetration into many nodes of a network, and could block signals as well as operate on their information content.

All of these capabilities could be attained with lower altitude satellites, of course, but at the cost of more satellites and intermittent coverage. Lower altitude satellites would be more susceptible to attack, and would have to be proliferated at great expense. This favors placing one or two systems in GEO. It goes without saying that such powerful weapons platforms would be able to destroy any incoming interceptor, and thus would be extremely difficult to disable.

The ability to perform such battlefield electromagnetic chaos at will is unlikely to be allowed to exist for very long before countermeasures are attempted. However, while front ends of receivers can be protected against burnout by careful design and use of front end shorting devices, they will not be able to operate while the jammer is on. Attaining jamming suppression ratios of 130 dB or more is not currently possible, as we see from the GPS problem at much lower attempted rejections. Thus while it may be possible for most enemies to prevent a second wave of burnouts after losing a generation of field systems, we can prevent them from operating as long as desired, or at the very least very seriously degrade their operation.

The already awesome capability of such systems could be made even more so by radiating greater power at lower weight and cost. It is highly likely that very large orbiting solar power stations capable of delivering energy to the earth will be build in space in the next several decades by the commercial sector. These system will be designed to collect and deliver hundreds to thousands of megawatts driven by market forces demanding clean, inexhaustible energy. These systems will likely use microwaves or millimeter waves for power transmission. It is not

likely that we could use such systems in a dual-use mode as space weapons, because they will be designed with broad beams in order to keep the energy density at earth low to minimize damage to people. However, if these systems sent their power to the space based weapon, and the weapon received only a fraction of the beamed energy due to the beam size at intercept, the weapon spacecraft could avoid the expense and weight of a power system, receiving and reradiating the beamed power from the power station instead.

A likely scenario is that these commercial systems will be developed in increments, with the first steps being orbital development test spacecraft capable of beaming "only" a megawatt or so, with following models at 10 to 100 megawatts. These will be used by the commercial sector as an "Orbital Power and Light " company, selling power to the Space Station and to orbiting commercial industrial facilities, after their test period is complete. The DoD could purchase power on demand from such systems, avoiding the need to develop and orbit huge power systems, or develop and emplace similar beam powering systems in orbit or on the ground. Under these conditions, the space based weapon spacecraft could well radiate a sizable fraction of the power beamed to it, which could be 1-10 megawatts or more, making it even more deadly that the 100 kW device assumed in the above example.

4.6.3 Space Based High Energy Lasers

High energy laser weapons, have been thoroughly analyzed and much laboratory work was done under the SDIO/BMDO program, however no such system has been fielded. This is for a number of reasons, some obviously political, but not a small factor is the high cost, large weight, and relatively few shots available from such systems. These weapons will become much more attractive in the future as a result of new technologies such as 20+ meter thin film mirrors and other techniques described in the EM weapon section, but used in conjunction with new technology phase conjugation correctors, shorter wavelengths, more accurate pointing and tracking techniques, and others. In addition they will greatly benefit from the expected major lowering in the cost of access to space.

These advances will enable lasers to attain much smaller spot sizes at longer ranges, lowering the energy per kill, and thus resulting in systems with reasonable mass and cost with capability for very many kills compared to current concepts. As a result, they could be utilized against a large number of high value surface, airborne, and space targets, and accomplish the attainment of complete denial of airborne superiority as a result of being able to destroy all high-flying aircraft at will.

In addition, and not the least, these lasers will of course be highly effective against tactical and strategic ballistic missiles in conjunction with a surveillance and cueing system, and attain a very favorable exchange ratio. If this surveillance system is integrated with the weapon platform, the true space "battle station" will have been born.

4.6.4 Disruption or Destruction of Enemy Satellites from Space

The ability of EM weapons to destroy sensors and receivers is more easily applied against unfriendly spacecraft, which cannot be shielded for long lest they not be able to carry out their function. Thus an EM beam force projection spacecraft is useful against space targets as well. This obviously also applies to laser weapons. In fact either weapon could be used in a

time-shared mode, since the number of spacecraft they would have to disable in time of conflict is probably far smaller than the number of surface targets against which they would operate.

Force application against other spacecraft can take other forms than beam power projection or physical attack. A number of techniques applicable from rendezvous space weapons have been known for many years though not yet implemented. Following rendezvous and station keeping with the spacecraft in question, paint can be sprayed onto optics, solar arrays, or radiators to disable the spacecraft covertly, assuming that our approach has not been detected. Likewise the spacecraft can be nudged or tipped gently in order to exhaust control fuel. Electronic interference is extremely easy from a few feet away, and takes negligible power. In short, homing interceptors may not needed, nor special warheads, if a capability is developed for a space weapon spacecraft capable of on-orbit control, with some form of proximity sensor and the specialized devices to cause the disruptive effects to other spacecraft.

This is one version of a space mine, albeit a nefarious kind because its action may never be detectable or provable, since its action results in failures much like normal failure modes of satellites.

4.6.5 Summary

In summary, in the next decade or two, new technologies will allow the fielding of space-based weapons of devastating effectiveness to be used to deliver energy and mass as force projection in tactical and strategic conflict. This can be done rapidly, continuously, and with surgical precision, minimizing exposure of friendly forces. The technologies exist or can be developed in this time period. The resulting capabilities would include denial of air supremacy at will, defense against ballistic missiles, and ECM/ICM on demand, and could radically increase the cost-effectiveness of the US forces in future conflicts.

5.0 Space Application Issues

5.1 Space Launch in the 21st Century

Samuel M. Tennant, Ivan Bekey

5.1.1 Introduction

In order to access space it is necessary to have a launch vehicle capable of propelling the spacecraft out of the atmosphere into space and providing sufficient velocity to achieve orbit. This was initially accomplished by using rockets largely derived from the ballistic missiles of the 1950s. NASA as part of the Apollo lunar program developed the Saturn launch vehicle which was the largest launch vehicle developed by the US. Subsequent to the Apollo program NASA developed the Shuttle, a two stage reusable manned vehicle that after re-entry lands aerodynamically like an airplane.

All of these vehicles utilize dated technology and operationally are labor intensive, expensive to procure and operate, and require an inordinate amount of time to prepare for launch. As a result of these deficiencies there have been a number of efforts to define a replacement vehicle for the expendable launch fleet. These efforts include the Advanced Launch System, the National Launch Vehicle, and the Spacelifter. The failure of these efforts to gain acceptance is attributable to the lack of consensus among the nation's space organizations and the fact these programs required a very large investment which is hard to justify in tight military budgets and other demanding national priorities.

Because of the Air Force emphasis on normalizing space and being able to operate in a militarily responsive manner, the growing obsolescence of the launch vehicle fleet and the high cost of operations, a number of studies have been conducted recently. These studies include the Space Launch Modernization Study (1994), a large effort carried out by the Air Force to explore future launch vehicle options. The most notable outcome of this study is the Evolutionary Expendable Launch Vehicle program which is presently in the RFP stage. A companion study was the SAB Space Launch Ad Hoc Study (1994) which addressed the technology issues relative to achieving future launch vehicles. NASA addressed the future launch vehicle needs of the agency in the NASA Access to Space Study (1995). Also during this period the Office of Science and Technology Policy put forth the OSTP National Space Policy (1994) assigning DoD the lead roll in the improvement and evolution of the current ELV fleet and NASA the lead for improving the Space Shuttle System and the technology development for reusable launch vehicles.

The New World Vistas Space Applications panel focused on the longer time frame and did not re-address the areas covered by these studies. The emphasis was put on defining future possibilities for the Air Force to gain access to space and understanding what key technologies might be enabling.

5.1.2 The Launch Vehicle Environment

The characteristics of current US space launch vehicles is shown in plate 1. The Titan, Atlas, and Delta launch vehicles were derived from ballistic missiles. The Titan II launch vehicle is a missile that has been slightly modified and refurbished, where as the Titan IV shares only some of the original technology but is a completely redesigned launch vehicle. It suffers from

having many configurations resulting from tailoring to the payloads and specific missions in order to achieve maximum performance.

The Delta has evolved through many configurations and today is probably the most dependable of the launch vehicles having not had a failure of the most recent configuration. The Atlas also comes in many configurations, and the Atlas-Centaur system has had two failures resulting in the lowest reliability of .86. All these vehicles require substantial on pad time to assemble and check out the vehicle, ranging from 50 days for the Atlas to 110 days for the Titan IV. The call up time, that is the time to assemble and check out the vehicle at the launch base, ranges from 90 days for the Titan II to 180 days for the Titan IV. The Delta requiring some 98 days and the Atlas which is shipped assembled at the factory is ready to go to the pad after receiving inspection. The logistic for all these vehicles are primarily contractor supplied.

The Air Force would like the on pad time to be no more than 3 days and have the payloads shipped ready to launch as encapsulated payloads that conform to standard interfaces. They would like to be able to carry out the launch operations with blue suit crews requiring the minimum of contractor support. These are all achievable objectives attainable with today's technology.

A more constraining characteristic of today's launch vehicles is their high cost which has hampered full utilization of space. The price of current launch systems is shown in plate 2. The word price is used instead of cost in that foreign launch vehicles are directly subsidized by their governments and thus do not reflect the true cost. Typically the cost per pound for US launch vehicles is on the order of 4500 $/lb to LEO, 10,000 $/lb to GTO, and 14,000 $/lb to GEO. As a result of the foreign pricing strategies and the trade policies, US launch vehicles capture only about 30% of the commercial market, Ariane (French) about 50%, and the remainder is divided between the Russians and the Chinese.

The typical breakdown of space launch cost is shown in plate 3. As can be seen the engines constitute the largest single item of costs and thus technology that reduces engine cost has the most leverage. On the other hand if one considers truly reusable systems then most of the cost can be avoided except the refurbishment and flight operations cost which to some extent are amenable to automation and modern data processing techniques.

The Shuttle, the only manned access to space the United States has, was initially configured in 1972 and had its first flight in April 1981. The program was originally sold on the basis that it would reduce launch costs and even more dramatic cost avoidance could be realized in that satellites could be recovered and refurbished for reuse. These economic arguments were based on a very large mission model that reflected all the speculative thinking of the time. Because of these strong arguments with Congress indicating the lower cost of Shuttle launches and the NASA policy to offer flights at a fraction of the actual costs, DoD manifested most of its payloads onto the Shuttle. After the Challenger disaster on flight 25, the future of the Shuttle changed. It was thoroughly re-examined and many design and procedural changes were introduced to improve the safety of the vehicle. Also the decision was made to essentially limit Shuttle flights to those flights where manned applications were involved.

Today DoD has switched all its payloads off the Shuttle in favor of the Titan IV. Shuttle operations are disappointingly expensive being on the order of $485 million per flight based on 7 launches per year. Much of this cost is the result of the extensive refurbishment required

between flights. As a result of their experience with the Shuttle, the DoD and Intelligence Community are reluctant to be tied to a manned vehicle, particularly one owned and operated by another agency. There is also a strong National concern over being dependent on a single launch vehicle.

In order to transfer from Low Earth Orbit (LEO) to higher orbits including Geosynchronous orbits and escape transfers, upper stages are used with the various boosters and the Shuttle. The primary stage used with the Shuttle is the IUS because its solid rocket motors are judged to be safe for use in the orbiter bay. The IUS is a sophisticated stage with multiple redundancy in its avionics and while it is highly reliable it is also a costly stage to use. The most powerful stage is the Centaur liquid hydrogen/ oxygen stage that was initially scheduled for use with the Shuttle until the Challenger accident. Subsequent to that event, liquid hydrogen/ oxygen was determined to be an unacceptable safety risk with the Shuttle.

The Centaur is used with the Titan IV to achieve Synchronous and high energy orbits. The Delta and the Titan use a number of solid and storable liquid stages. A common practice is to provide the stage with the booster to burn into the transfer orbit but then have the spacecraft provide the final apogee kick motor. These stages and in particular the Centaur represent a substantial fraction of the space access cost, so it is also important to address how in the future these costs can be substantially reduced.

5.1.3 Immediate Future Plans

The DoD is moving ahead with the Evolutionary ELV concept that is to replace the existing ELV fleet with a single family of Expendable Launch Vehicles with common subsystems, and is to achieve high reliability, low cost and improved operability. This current plan provides the IOC for the MLV capability in the fall of 2002 and the IOC for the HLV early in 2005. The critical technologies include reduced cost main propulsion, fault tolerant avionics, electromechanical actuators to replace the present hydraulic ones, onboard vehicle health management and advanced guidance, control and navigation system, aluminum/lithium alloy tank assemblies and automated launch operations. If the Evolutionary Launch Vehicle program is continued to its completion, it undoubtedly will be the expendable launch vehicle for a minimum of the next twenty to thirty years.

NASA is pursuing the technology of a Single Stage To Orbit (SSTO) reusable vehicle. They have released three, fifteen month study contracts to assess the feasibility of achieving a practical SSTO. These contracts call for developing a full-scale conceptual design as well as developing a subscale SSTO that can demonstrate the feasibility of the concept. In parallel they are developing the critical technologies which include advanced thermal protection systems, aluminum-lithium tanks, composite structures and hydrogen tank, tripropellant propulsion and lightweight engines.

While design studies show that with current propulsion and the new lightweight structures it is possible to achieve a SSTO with practical lift capability, the key issue is whether the technology can support true reusability, that is, refly with the minimum of servicing and not require recertification in the manner the Shuttle does. We are talking about thousands of flights not hundreds before major overhaul.. If this can be truly achieved, then the cost of space access could be reduced well below a thousand dollars a pound. This would rapidly accelerate the

commercial development of space and reduce the cost of a major portion of the military space program, in that the MLV class payloads probably would be launched on the SSTO because of their compatibility with the volume constraints.

NASA's approach to the SSTO is a partnership with industry where the vehicles would be operated by industry and they would also share in the non recurring development costs. In this scenario one can envision the Air Force using the SSTO for routine MLV launches, large expendables for the heavier payloads and having a reserve expendable capability for reconstituting orbital constellations during time of war.

A key item that will have to be developed is the orbital transfer stage in that most military satellites are in orbits higher than LEO. If this stage is expendable it will add appreciably to the cost of operations. On the other hand if this stage returns to the SSTO and is recovered and returned to earth it may provide for lower cost operations if the infrastructure to support the recovery is not too costly of an investment. Electric ion, plasma, and solar thermal engines are technologies of today that can be applied to the orbital transfer problem, however their low thrust levels equate to long transfer times and thus are applicable only to certain scenarios. In all likelihood LOX/ LH_2 technology will continue to be applicable to most of the military orbital transfer operations.

5.1.4 Launch Vehicles of the More Distant Future

Ultimately hybrid air breathing/rocket transatmospheric space vehicles will come to age. This type of vehicle can provide routine access to space at reduced cost, increased operational flexibility both on the ground and in flight, and high reliability. Many of these attributes stem from the airplane characteristics of this vehicle, such as lifting body, air breathing propulsion, horizontal takeoff and landing, and so forth. The single stage to orbit airbreather/rocket combination is an airplane that goes into orbit and as such can be expected to accrue many of the desirable operational characteristics associated with contemporary high-performance aircraft.

The reference vehicle used in the NASA Access to Space Study has a baseline propulsion system derived from that being developed by the National Aerospace Plane (NASP) Program. The reference vehicle uses a special low speed propulsion mode, ramjets, and supersonic combustion ramjets (scramjets) for primary propulsion along with LO_2/LH_2 rocket augmentation in the low and high speed regimes of the ascent trajectory. These vehicles are typically large vehicles, this particular reference vehicle has a gross lift-off mass of approximately 900,000 pounds and a dry mass of approximately 240,000 pounds. The payload bay has a usable volume of 15x15x30 feet, and the payload capability is 52,000 pounds into 100 nautical mile orbit at 28.5 degrees inclination.

Transatmospheric vehicles will be far more than spacelifters, they will be capable of carrying surveillance and strike missions anywhere on the globe in times measured in a few hours or less. These vehicles will be expensive and few in number, but their capabilities will make them a vital part of the future Air Force global reach, global power capability.

The future of the transatmospheric vehicle lies with the enabling technologies which span material sciences including both metals and composites, new propulsion systems including linear rockets, variable Mach number ramjets, and scramjets, advanced passive and active thermal systems and high speed computational capabilities needed to control and configure the vehicle.

Considering the scope and the needed progression of these technologies, a practical and operational useful transatmospheric vehicle is probably beyond the time frame of this *New World Vistas* Study.

5.2 Use of Commercial Capability

William M. Mularie, Robert Rosenberg

5.2.1 Background

The current explosive growth of commercial digital systems for broadband communications, information and entertainment signals a rapidly increasing gap between these commercial systems capabilities and that of our military and intelligence communications and information systems. The development of these systems in the context of a business and consumer-driven market(high volume/ low unit price) ensures widespread global access and use to these capabilities. For example, the Chinese will have all 26 provincial capitals, except Lhasa in Tibet, tied into a fiberoptic, digitally switched broadband network with Hong Kong, Singapore and Thailand by the end of this year. Even in developing countries, the investment in telecommunications will exceed $ 300 B over the next 5 years in phone lines for 90 million new subscribers. These numbers do not reflect the growing wireless investments by developing countries, leapfrogging the investment in the conventional hardwired information infrastructure.

Universal access to low cost computing power (not the $1500 artificial price structures being maintained by PC manufacturers) will be delivered by the video game industry. For example, Nintendo has released a 20Mhz, 32 bit RISC-based machine, 3D graphics, stereo sound, 2 displays and controller for $199[1]!!

In parallel to this remarkable revolution in information technologies , space missions are also becoming more fiscally appealing to the commercial sector. Industry leaders have begun to step forward and actively increase their pursuit of commercial space systems. Many foreign nations and companies are reaching to space just as quickly and with growing success. There has been a resultant increase in the amount of high resolution imagery, worldwide "cellular-type" communications, and commercial space-lift capabilities that are granting access to space for more and more nations. "Commercial Space" is simultaneously coming of age with "Information Warfare"[2]. The relationships between the two will have a profound effect on all future conflicts and will require innovations in the way we procure, operate and exploit space systems.

5.2.2 The "Dark Side" of the Global Revolution

Most observers view the communications/ information revolution as a positive trend, insuring greater worldwide communications connectivity and real-time access to disparate information sources, improving business efficiencies and improving human quality of life.

However, those charged with our national defense must also consider the threats implicit in this new age. In the near term, it is clear that the relative benefits of this revolution will fall disproportionately upon our enemies in that; access to worldwide advanced communications, computer processing and information and surveillance systems, previously denied due to the barriers of high entry costs or infrastructure deficiencies, will be assured. For example, in the recent capture of the Cali drug cartel leadership, it was discovered that the Cali counterintelligence computers had penetrated the International telephone switching networks and were monitoring Federal Drug enforcement activities, such as wiretaps, against them. Without the burden of the

DoD acquisition processes and the Federal Acquisitions Regulations (FAR), our enemies can acquire the state of the art while the DoD fields information and communications systems that are outmoded by several commercial generations.

5.2.3 The Future the Level Playing Field

By the end of this decade, consumer broadband communications channels, desktop supercomputing power, processing software and widespread information sources (imagery, GPS,...) will be ubiquitous:

- Computing Power: Teraflops on the desktop
- Worldwide Broadband Communications/Information -Direct Broadcast Satellites
  - Communications Constellations (Iridium, GPS, ...)
  - Imaging Satellites (Eyeglass, ...)
  - Wireless Communications (28Ghz,..)
  - FiberOptic Communications
- Worldwide, real-time access to information: Imagery, GPS,...

The irony of this emerging threat is that many of these advanced multisensor and communications capabilities were initially developed and financed by the DoD. As the cartoon character Pogo once mused, "We have met the enemy - and he is us!"

Now, because of the development of commercial market appetite the private sector investments, estimated for 1994 at over $1 Trillion, the DoD's ability to maintain an incremental technology advantage by means of capital spending. The government is now a small user, rather than a market driver.

A rough graphical representation of the problem the DoD faces is shown below: The graph compares "system performance" (e.g. communications satellite bandwidth) as a function of time (years). The graph (Figure 5.2.1 The Growing Performance Gap Between Government and Commercial Communications Systems) shows the lead by the government systems has been overtaken by the commercial systems.

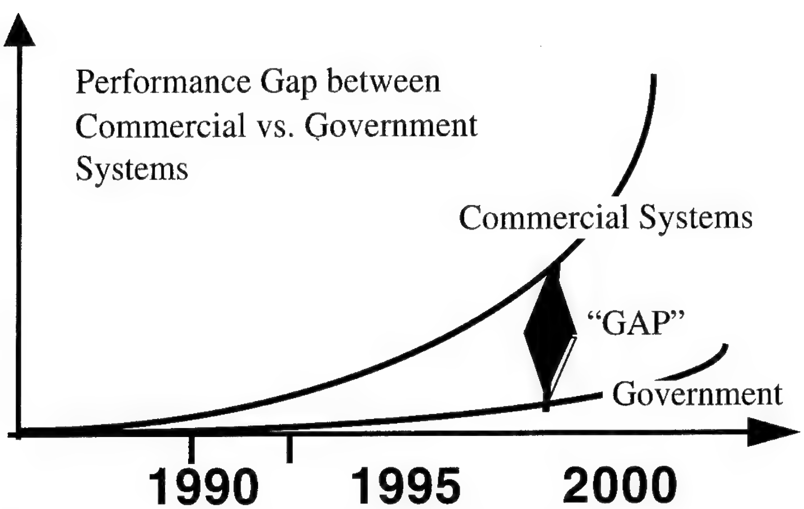

Figure 5.2.1. The Growing Performance Gap Between Government and Commercial Communications Systems

The sense that one should make of this representation is that there is a substantial and increasing performance gap between the commercial information systems (e.g. Direct Broadcast Satellite, etc.) and the government- developed SATCOM architectures. This reflects the large and growing disparity in commercial and DoD investments.

5.2.4 Appllications to US Military Space Systems

To support the military, as a whole, we need to consider first, the ability of commercial systems to reduce the overall cost of maintaining a minimum force level. Second, we need to consider applications of commercial systems to peacekeeping and limited regional conflicts, primarily in the reduction of deployment costs. Finally, we need to look at commercial systems from the other side and examine the drawbacks of these systems in there added value to potential adversaries and how this degrades from their overall utility.

There are a variety of potential benefits to the US military resulting from the increased development and deployment of commercial space systems. As highlighted in Table 5.2.1, these can range from a decrease in future military space system development costs, providing opportunities to share missions or to hitch along as a secondary payload, to maintain a strong US industrial base to support space systems, and to increase the ability to train and exercise our troops.

The US military should thus expect to benefit from the commercial industry's profit-driven thrusts to reduce costs and streamline development costs for their space systems. The Air Force should focus on becoming a better customer by learning from industry as they "strip the fat" off the years of increasing space costs. If "faster, better, cheaper" is possible, the commercial sector will find a way to make it happen.

As a side benefit of the commercial space industry, the US will be able to retain its technology leadership and the skills, facilities and tools in these times of reduce budgets. Many aerospace companies have greatly reduced or eliminated in response to government cutbacks. With proper planning, the commercial space initiatives can allow for the US to retain a formidable Technology Reserve similar to the Military Reserve that can be called up rapidly in times of need.

The large number of commercial space launches and satellites planned for the next ten years will provide an opportunity to fly secondary payloads both as operational systems, or more possibly, to demonstrate new space technologies. The large cost of conducting space experiments has limited the Labs and others to space-qualify and demonstrate new technologies. The technology back-log for items "almost-ready" is growing as fewer and fewer opportunities arise. Even with ideas such as STEP, Mighti-Sats, ISTF, and others, SPOs and other space agencies are reluctant to infuse new, unproven technologies in their designs. Use the commercial launches as opportunities to demonstrate new/ready technologies might be a large cost savings both in terms of reducing space demonstration costs and in enabling new technologies for operational systems.

Table 5.2.1 - Benefits of Commercial Space Development to US Military

Potential Cost Benefit	**Description**
Reduced Space System Development Costs	Improved Manufacturing Techniques and Facilities Streamlined Practices - Trim-The-Fat Profit-Oriented Approaches Standardized Products (Busses, Interfaces, Launch Vehicles) Cheaper, Production-Line Units
Increased Availability and Capability Of Commercial Equipment, Tools And Techniques	Reduce Need For Government To Develop Specialized Tools Consumer Demands Will Require User-Friendly SW And Hardware Cross-Training With Other Disciplines -- Reduce Need For Specialized Training
Reduced R&D Expenses	Commercial Need To Reduce Costs And Increase Capability Industry Will Fund Research In Key Areas - Spacelift, Bus Technologies, Communications and E/O Payloads Military Spending Can Be Focused On Military Technologies, Payloads And Applications Number of Launches Provides Increased Opportunities for Labs To Space Demonstrate Technologies as Secondary Payloads
Retain Technology Reserve	Keep Facilities, Tools, And Skills Active Training And Cross-Breeding Of Lessons Learned Keep Ranges Active
Increased Readiness Of Military Personnel	Embedded Skills As Part Of Pervasive Knowledge-Base Increased Availability Of Training Centers Better Training Materials, Educators and Facilities Training On Real-Systems Will Become More Common

5.2.5 Working with Commercial Industry

One of the largest areas of opportunity for cost savings will result in the sharing of research and development costs. The high costs traditionally associated with space technologies has generally limited their advancement through government-sponsored projects or IR&D studies. With the increased drive to maximize the profitability of commercial space systems, industries will be more willing to invest their own dollars in R&D activities. The opportunity for the US Government to share or be a "secondary benefactor" will increase as commercial space grows. How can this be accomplished? It is clear that to fully realize the potential DoD and industry must change their behaviors and do business in new ways.

For example, the DoD cannot invest in emulating, replicating or maintaining the worldwide commercial broadband backbone but must invest in *value-added functionality* to lift the DoD above the commercial curve. Invest in building the fastest car not in building the race track. As seen from Figure 5.2.2 the DoD investment in systems for which the commercial market is in the lead (e.g. information systems) should lie in value-added functionality not in systems replication (catch-up).

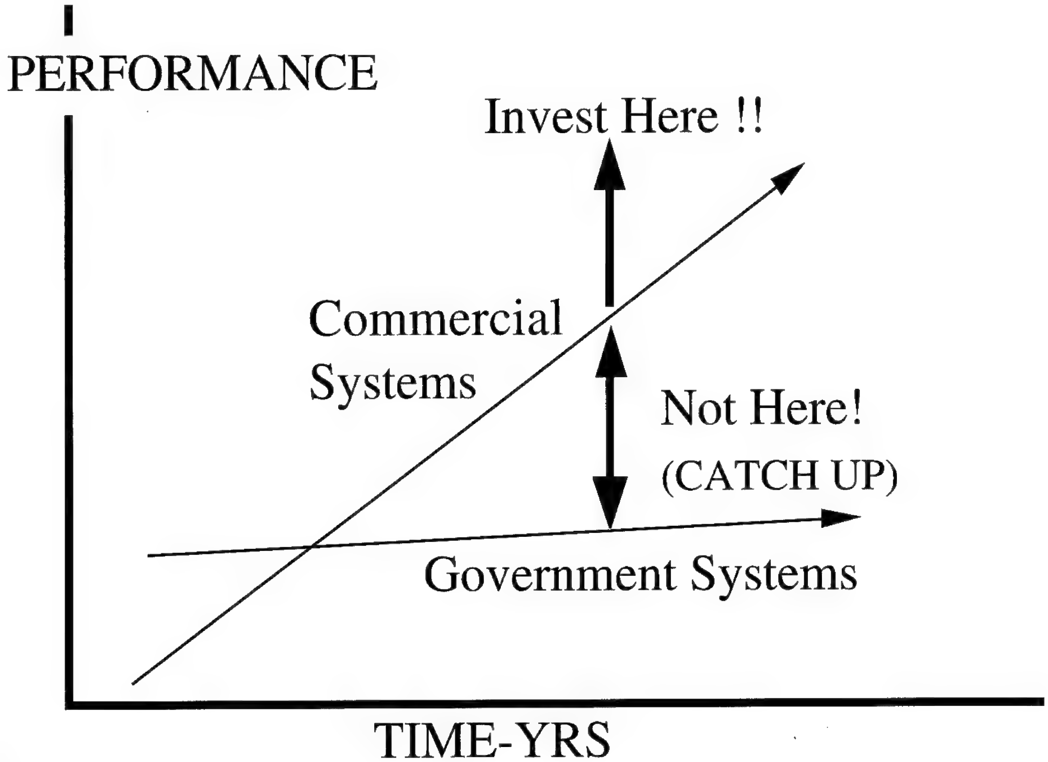

Figure 5.2.2.

This imperative was a major conclusion of the Carnegie Commission report:

- Secretary of Defense, William Perry, summarizing the Carnegie Commission report on the future of the Defense Industrial base argues for a "merger" of the commercial

industrial and defense industrial bases. The US is the only industrialized nation with a separate commercial and defense industrial base. We cannot afford this luxury in a financial sense, but more critically, in information technologies, the current defense base is years behind US commercial industry in technology and commercial practice. To better define the impetus for commercial/DoD interactions, consider the following :

What is a commercial company?

A working definition: A ***commercial*** company is one which can ignore the DoD market and still remain financially viable. The focus of a commercial companies is the fight for customers in the global commercial market. This excludes most of coterie currently surrounding the DoD program offices and includes most of the Fortune 500.

Why Should the DoD work with Commercial Companies?

Only in specific markets should the DoD work with commercial companies; information technologies is such a market—the ballistic missile market, for example, is not. The unfortunate fact is that the global commercial markets is far outpacing the investment and capabilities of DoD, as outlined above. The DoD must have access to commercial development as a baseline for its investment to obtain incremental advantage over the enemy.

Why should a commercial company work with the DoD?

This dynamic is misunderstood and not recognized. The answer is not profit. In addition, the Draconian procurement and accounting systems placed upon commercial companies is a severe disincentive. However, US commercial companies will work in a meaningful way with the DoD for the following reason:

Marketing Risk Mitigation

Major corporations take the process of parsing their R&D $$ investment into various product development options with great care and trepidation. Placing this corporate "seed corn" in the wrong places, in the development of the wrong products or services, can put the entire corporation at risk of failure. This process is not an exact science; consider the history of Wang, DEC an d IBM.

To mitigate this risk, corporate management look outside their walls to the customer base for affirmation of their R&D investment directions—the exercise referred to as "marketing". The DoD represents an attractive test market for new development ideas, because:

- *DoD requirements that are typically ahead of the rest of the commercial market. DoD systems must go faster, farther, be more stable, robust, ...etc.*
- *The DoD has the capabilities to test concepts-it is a vast, responsive test bed for new development ideas*
- *The DoD pays its way--it brings development $$ with its participation*

Thus the DoD represents a very attractive test market for exercising the viability of commercial development ideas, thereby minimizing the corporate risk. This does not mean that commercial companies view the DoD as the ultimate customer, even if the development is successful. The DoD, in general, represents a small customer base with a very difficult purchasing interface.

The benefit of this relationship, however, does not fall only to the commercial developer. Several of the commercial R&D developments which the DoD is exercising will be useful to give the DoD added capability. As a co-development partner, the DoD can influence modifications of the commercial development direction to give the DoD capabilities over the commercial implementation; for example, by development of a specific interface which is interoperable with DoD systems. *These DoD-specific modifications can be implemented at low cost, or no addition cost, if done early in the co-development cycle. Attempting to change COTS products to DoD specific needs is a lengthy, expensive process.*

5.2.6 Conclusions

In summary, there are many direct and secondary benefits to the US military that will results from commercial space system development. In addition to the retention of key resources in a technology reserve, the pooling of research dollars will insure that the US maintains technological leadership in space.

In order to reach this new world, the DoD must change the way it does business with commercial developers. New relationships must built around greater personal interaction of DoD and industry partners early in the development cycle.

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5.3 International Space Developments

Donald Lewis

5.3.1 Introduction

The increasing worldwide availability of space technology and services applicable to military space systems portends a future in which military access to space is affordable, broad, and brokered through many global institutions. This places a burden on the authors of national space policy and the architects of national security space systems to acknowledge and accommodate the internationalization of space as it affects US military advantage from the exploitation of space. The purpose of this paper is to describe the current and likely global environment for proliferation of space technology and its applications, and the resulting pervasive access to space available to support foreign militaries. This effort is little more than a quick view to the future. More robust and insightful examination of the projected evolution of international commercial and military space should be undertaken by responsible organizations. Consistent with the limitations of this effort, this paper concludes, not with specific prescriptions but rather with the highlighting of several key considerations for those involved in establishing national space policy and architectures.

This paper was written at the request of the US Air Force Scientific Advisory Board's Space Applications Panel following a briefing on the same subject by the author in June 1995. It captures the principal messages of that presentation without the classified substantiating examples and evidence provided in that briefing. This effort was sponsored by the Air Force Materiel Command's Space and Missile Systems Center, Developmental Planning Directorate (SMC/XR) with many valuable and substantive contributions made by Col. Robert Preston, SMC/XRT.

5.3.2 Some Issues and the Players

The issues involved in this paper's topic are not new, but have become more pressing as the country's national security infrastructure truly transitions away from the Cold War paradigms and planning for new futures is initiated. The issues arising from the internationalization of space are but just a part of the many developments that will affect the outcome of those planning activities. Among the many observations made by the author while studying the topic, the following four seemed key to capturing the essence of those issues.

First is the broad global distribution, or internationalization, of space technology stimulated through various means of technology transfer. As discussed in the following section, classic technology transfer through export is only one of several mechanisms that have contributed to a global understanding and exploitation of space technology and its applications. As a result, space technology has become virtually a global commodity with many commercial sources.

The second observation is that there are increasing global opportunities to gain access to space to support commercial as well as national security objectives. Approximately seven countries can currently launch satellites, some twenty own satellites, and at least eighteen have the ability to construct satellites (and even more manufacture satellite components). There are some fifteen consortia and joint ventures currently flying satellites. Due to the global nature of the services provided by communications, navigation and weather satellite programs, every

country in the world has access to space. Furthermore, virtually every country has, to some degree or another, taken advantage of that access; be it for commercial or national security purposes.

The third observation is that there is increasing evidence of growing influence and military utility of both domestic and international commercial space services and applications in comparison with those of many dedicated military space systems. Already international commercial communications satellites have more capacity, offer more extensive service options and utilize more advanced communications protocols than military satellite systems. Demands for service to mobile users and for efficient use of limited spectrum are creating commercial communications systems with the robustness and resiliency to interference appropriate for military command and control. The growth in this particular commercial sector is driven by profit opportunities in the yet-to-be saturated global market for communications. The commercial sector also provides significant enhancements to GPS navigation services, and several commercial remote sensing satellite programs are under development that will exploit untapped international markets for space-based imagery. In general, it is the agility of the international commercial sector to assimilate technology in response to changing market conditions, far exceeding that of traditional military space, which poses significant challenges and opportunities for US planners.

The last observation is that there is an ever increasing assimilation of space-based applications by foreign military commands. Countless authors have pointed out how the Gulf War demonstrated to the world the value of space support to military operations. In fact, over the last decade there has been a slow, but steady, incorporation of space-based support functions into militaries throughout the world. The Gulf War has only accelerated that evolution through the demonstration of the efficacy of space in a real, modern war fighting environment. Furthermore, there has almost certainly been a recognition on the part of various foreign states that the US has become dependent on space to support critical war fighting capabilities. Thus, the vulnerability of US space assets to foreign compromise has been increased through a broader global understanding of the value of space to military support. This increased threat is not limited to US space assets but all international programs.

The preceding observations lead to the postulation of a number of potential consequences that may result from the global proliferation and application of space technology. There are certainly others, but those listed here serve to illustrate the environment which US national security space policy must accommodate.

Enhancement of conventional foreign military forces.

Increase in foreign space forces.

Increased threats to US and allied space forces.

Complex technical and institutional interrelationships between the providers and users of international space services.

Decrease in US space industry market influence.

The force multiplier effect provided by space has only just become apparent to the foreign military strategist, particularly with the demonstrations provided by the Gulf War. The potential for enhancement of conventional fighting units through the application of satellite

communications, navigation and weather services is not lost among most military commanders. The degree to which such enhancement is realized throughout the world is dependent upon many factors and circumstances. Virtually every military is resource limited and thus forced to make weapon and infrastructure expenditure decisions that maximize their perception of force enhancement in the context of their expected war fighting environments. As the effective cost of space support to the war fighter declines relative to other force enhancement alternatives, more foreign militaries will incorporate space-derived support into their military doctrine and operations. In addition, they may do so with substantially shorter development cycles in systems, tactics, and doctrine and with surprising applications of space to their militaries. They will have arrived at useful space capability without having to re-trace the development steps that US and Russian militaries took. They will be able to buy from commercial suppliers of services and systems, unencumbered by political and institutional "baggage" and attachment to past investments and old ways of doing business.

In the near-term, the functional areas most likely to see dramatic cost reductions due to market forces (primarily as a result of commercial competition) are satellite communications, weather and navigation. Remote sensing will follow as its nascent commercial sector matures. Extensive utilization of intelligence (other than remote sensing imagery) and early warning support from space will lag due to their almost purely military nature, thus requiring dedicated national security funding.

As some foreign warfighters become more reliant on space for force enhancement, more dedicated foreign space forces will be created. These organizations have the responsibility for the acquisition, operation and protection of military space support elements. Current examples include Russia, China and France, each which has well-established military space organizations. Other nations will create similar organizations once they have bought into and come to rely on space as a significant element of their national security. Although there appears to be a global trend toward commercial suppliers of space services, foreign space forces will necessarily be driven to establishing protective doctrine for those support elements that have become critical to their military force structure; except where commercial suppliers are able to assure them of robust, reliable service. The need to ensure the availability and functionality of space support elements will cause such organizations to seek survivable services, alternate sources of support, and defensive countermeasures.

It is not a large conceptual leap to go from a defensive posture to considering developing offensive measures with respect an adversary's space assets, particularly where they are clearly identifiable targets, distinct from commercial utilities. The increasing pervasive understanding of the value of space to the war fighter (and to national well being in general) necessarily leads to more opportunities for potential adversaries to recognize the value in degradation and denial of such. The increase in threats to US and allied space assets comes not only from this broader potential understanding of the reliance of space (for targeting purposes), but also on the proliferation of the underlying technology to perform counter space activities.

In discussing the implications of the fourth consequence, that of complex international relationships, it is important to consider the nature of the players in the international environment. The early days of space saw only those few countries that could afford the high costs of space develop national space programs. The requisite government involvement essentially limited the missions to military and scientific for many years. The first commercial endeavors were highly

subsidized by national governments and a few consortiums of national governments (for example, Intelsat). Thus, the majority of space programs were developed or sponsored by individual national governments. Today, although many space programs are aligned on a sovereign state basis, there are many other owner/operator groupings that are indicative of the future spectrum of players.

There is a decreasing proportion of space programs owned by individual national governments. As the international business environment creates increasingly complex financial and ownership relationships it is only natural for such complex interrelationships to be extended to the ownership and operation of commercial space systems. Furthermore, as more countries attempt to reduce their cost of access to space for scientific and military purposes there is the potential for joint ventures for non-commercial purposes both long and short term. The European Space Agency, ESA, is probably the largest single example of a foreign joint venture in that regard. From another perspective, dual-use programs such as the French Telecom and Spanish Hispasat communications satellite programs inherently offer the potential for extremely complex mixing of commercial and military interests. Some of the current and potential future categories of players in the international space environment include: sovereign states, state consortia, commercial consortia, commercial enterprises, allied coalitions, and criminal organizations

There are some interesting potential consequences of this roster of players. Consider a time of crisis or conflict during which the determination of satellite ownership becomes necessary. That may be extremely difficult in cases involving joint ventures since such organizational constructs may cross several national borders. Further, if the objective is to get the owner(s) to deny service or access to an adversary, it may prove impossible when the ownership is multinational or highly fragmented. However, difficulties in determining ownership may pale in contrast to determining the user clientele of such systems.

For example, it may become impossible in an increasing number of circumstances to sort out allied and adversarial use of communication satellites from US use. This becomes critical when precise targeting information may be required for exploitation and service takeover and denial. However, it may be difficult to garner sufficient legal recourse for the preemptory takeover of some space services due to the interrelationships between commercial and government ownership, again with substantial potential for cross border implications.

The consideration of allied coalitions and criminal organizations as players in the international space environment is somewhat new to the space policy arena. Allied coalitions should be considered an example of short-lived relationships in which multiple users share a common military objective and more importantly share common space support elements. Integrated common operational standards for ensuring interoperability, and command and control become important issues under such circumstances.

With respect to international criminal organizations, they often have resources far greater than the government organizations that they are subverting. Their utilization of space for their various "business" purposes should be considered a given. Examples abound in the areas of satellite communications and navigation. Although their ability to purchase services globally will continue to grow, it is their increasing potential and motivation to purchase the technology to either counter military and law enforcement use of space or to purchase and operate their own programs (albeit covertly via commercial cover) which becomes more problematic. Particularly

worrisome is that they will be able to purchase commercial services qualitatively superior to dedicated systems currently available to law enforcement and military agencies.

The last consequence addressed is the declining international market share held by the US space industry resulting from, among other things, more and more commercial and military buyers and sellers in the global space market. Technology obtained from export and indigenous development is increasingly available for assimilation into foreign manufacturing infrastructures. Many developing countries see involvement in space technology as an avenue for enhancing their emerging high tech industries and thus they aggressively pursue opportunities. Industrialized nations with mature space industries, once highly subsidized, now more openly and aggressively compete for international sales. The end result will be more suppliers in the international market thereby reducing the market share available to US industry. Currently the US is generally considered the supplier of choice when that choice is based on quality or technological superiority. However, the choice is often dictated by a combination of international and domestic political considerations that tend to favor other sources. This allows non-US suppliers the opportunity to gain on-orbit experience and feed back the lessons learned into improving their product quality.

In closing, the development of future US national space policy and national security space architectures must acknowledge and accommodate this larger international environment that strongly influences the efficacy of all national security space capabilities, regardless of the country in question.

5.3.3 Technology Transfer

One of the implicit consequences of the internationalization of space is the global proliferation of space technology and applications. Thus, the issue of technology transfer is a critical element that must be understood by those responsible for planning future US space policy and architectures. The purpose of technology transfer policy should not necessarily be to retard the transfer of US technology, but rather to assure that the eventual result of such inevitable transfers, whether from the US or foreign sources, maximizes the opportunities to influence the global environment consistent with US national space policy objectives.

Thus, it is important to consider this issue from a global perspective rather than being concerned only with US space technology exported abroad. Increasingly, the industrialized world is aggressively marketing its own space technology as the global market for high technology as a whole becomes broader. The French government, for example, created PROSPACE (a subsidiary of their national space agency, CNES) to actively market their national space industry's technology worldwide. Increasingly, space technology is bought and sold as a commodity rather than as advanced, novel capabilities. The maturation of much of that technology has been accelerated by the international commercial sector, a growing influential factor in technology transfer.

In recent years the control of technology export from the US has been heavily influenced by concern for regulating the proliferation of technology related to weapons of mass destruction and the incorporation of advanced technology into conventional weapons. This preoccupation with near-term, first order effects has obscured the need to carefully examine the implications of technology transfer in the larger context of evolving international capabilities and the appropriate link between control policy and national space program objectives.

There is a strong global "diffusion gradient" for technology in general and space technology in particular, given the prevailing economic opportunities. Those states (and their commercial sectors) possessing technology seek to maximize their return on investment through the sale of such technology to those that find it cheaper to buy into the club rather than develop from scratch their own indigenous capability. With many commercial concept-to-application cycle times measured in tens of months (as compared with years for traditional national space programs) and the rapid depreciation in value of older technology, it is no wonder that technology proliferation is so pervasive.

One of the consequences of the space environment becoming increasing dominated by commercial enterprise is the demand for technologies that impart competitive advantage to the owner/operators. This is currently fostering a commercial sector that is more responsive in taking advantage of technological opportunities than the traditional government-sponsored national security space institutions. The projected net result will be an increasing dominance of commercial space both in terms of gross service capacity and service performance.

Apart from the classic technology transfer that occurs when technologies in the form of goods, services or technical assistance are sold to another country, there are several other means by which technology "diffuses" across national boundaries, often with little or no monitoring or control. These range from trade off-sets between the US and favored nations to university and professional training and education. For example, as a condition-of-sale to some foreign countries, the US industry must also provide training to the recipient country on how to repair, maintain and eventually manufacture their own components and subassemblies in the future. The providing of such training and start-up of indigenous capability as a condition-of-sale has become much more prevalent in US space technology exports in the last couple of years.

Training in space technology, applications and operations is provided worldwide through universities and similar institutions and is virtually unregulated. Many thousands of students are taught the basics of space technology through countless engineering programs. Many of these programs have opportunities for students to obtain hands-on experience working on small satellite projects under the auspices of experienced aerospace industry instructors. These programs are not limited to the U. S. The University of Surrey in the United Kingdom, for example, has become a world leader in the development of small satellites through its training program. Portugal purchased its first satellite, POSAT-1, from the University of Surrey in 1993 along with on-site, hands-on training for Portuguese engineers during its construction.

The pervasiveness of space technology will continue for the future; particularly for technology supporting commercial enterprise. That technology that is more limited in its applicability to military space functions, i.e., missile warning, electronic intelligence collection, will be much less prone to wide spread availability due to lower demand. The issue at hand is to appropriately assess both the downside risks associated with global technology proliferation and the upside opportunities that may exist to provide military advantage to the US. It should be pointed out in closing on this subject, that there is no linkage between the establishment of national security space policy or architecture objectives and the control, positive or negative, on technology export from the US or elsewhere.

The concept of negative control of technology transfer is fairly clear; restrict the flow through various institutional mechanisms. In recent time, this approach has been less and less effective. The concept of positive control over technology transfer is much more innovative and charts new ground in global influence. Influence is one of the primary purposes of positive technology control. Conceptually it ranges from diplomatic initiatives to control foreign access to space by encouraging institutional outcomes favorable to the US military and commercial interests to striving to dominate the international space services market place through aggressive marketing. Influence can be achieved through direct economic means; lower prices and subsidization of expensive services ("freebies") and through technological means; adoption of US hardware and software standards and specifications and licensing stipulations; and through policy impacts on regulatory risk and opportunity perception by investors. The key to achieving positive technology proliferation control is linking the need for influence and its manifestations back to national space policy and to planning for US civil, commercial and military systems.

5.3.4 International Access to Space

The purpose of this section is to outline, at best, the vast, growing domain of international space services and applications and the opportunities for foreign military utilization. There are no new revelations suggested here, but rather a picture that portends the continued prevalence of military space throughout the world. For more authoritative and quantitative assessments there are a number of market surveys and forecasts depicting the future market potential for space technology and applications that can be consulted. Consistent with the previous two sections of this paper, the message is that the space planner should not only be concerned with the negative aspects of the foreign military exploitation of space but also the opportunities that may be present for ensuring superior US access to space.

The basic functional areas listed below are used here only to serve as a means for organizing the following discussion of commercial and military space applications. The sections that follow briefly describe some of the more interesting facets of international access to these functional areas. A more comprehensive treatment of this topic with pertinent examples can be obtained in classified forums.

5.3.4.1 Navigation

Space-based navigation has become one of the principal examples of a military support service evolving into a broad, global commercial application. The geolocation service provided by GPS has become a virtual utility, available to all those that can afford the relatively inexpensive receivers. The availability of such receivers world-wide has made it possible for essentially every foreign military to obtain them, resources permitting; the resources required having become nearly negligible. The Gulf War and other regional conflicts have highlighted the intrinsic value of accurate, personal navigation support to the war fighter. The Russian GLONASS system is a similar space-based navigation service that, although it has not caught on in popularity, has also contributed to the broad understanding of the military value of space-supported navigation services.

The effectiveness of the commercial sector in rapidly exploiting the economic opportunities in space services is exemplified by the growth in geolocation applications and associated enhancements. For example, Selective Availability, a secure means for providing higher accuracy

GPS geolocation capability to US military users, has effectively become circumvented through the international commercial marketing of differential GPS services. This is an example of how the commercial sector, driven by market opportunities and pressures, provides services equal to or exceeding those of the military sector.

Clearly one consequence of the pervasive use of GPS will be the development of special warfighting applications utilizing accurate geolocation. Of special concern are the development of precision guided munitions and high accuracy ballistic missile guidance systems. In addition, incorporation of GPS receivers on spacecraft will permit more autonomous attitude and tracking functions. Already such experimental systems are being flown by foreign space programs. This will enable access to improved remote sensing and intelligence collection products obtained through higher accuracy satellite geoposition and geolocation information.

The growing, well-known reliance on GPS for both commercial and military purposes establishes such services as potential targets. The potential threats to space-based navigation and geolocation are increasingly becoming more widely recognized. It is likely that some adversaries will give thought to degrading or denying such services; albeit with the potential for inflicting interference with their own use of those same services.

5.3.4.2 Weather

Satellite imagery of global weather patterns has been available throughout most of the world for several decades. Weather imagery data is available virtually everywhere and easily supplied and incorporated into military operations. In addition to the US programs, meteorological satellites are operated by the European Space Agency, Russia, India and Japan with China soon to follow. To facilitate global utilization of weather data for peaceful purposes, international standards have been established for common data downlink formats. More sophisticated services providing atmospheric sounding, sea states, winds and oceanographic data will become more prevalent and also probably freely available from both US and foreign programs. The foreign military commander is therefore likely to have broad access to increasingly sophisticated meteorological data from space from which to obtain significant military benefit. Like space-based navigation services, space-based meteorological services are becoming utilities with broad, global constituencies.

The sensitivity to providing weather information to ones potential adversary is exemplified by India's encryption of weather imagery from their geosynchronous weather (and comms) satellite program, INSAT, to preclude its exploitation by Pakistan. The downside of this policy seems to be that it has precluded India from sharing their weather data with other countries and entering into the commercial market for ground receiving equipment. India is now considering broadcasting their satellite weather data in the clear; particularly since Pakistan has access to other sources of satellite weather data reducing the value of the encryption as a defensive measure.

5.3.4.3 Communications

Probably the fastest growing segment of the international space services market is communications. The evolution toward global interconnectivity has inspired consideration of novel uses of satellite systems integrated with the terrestrial communications networks. There are several important developments and trends in satellite communications support to the warfighter. A few of those are mentioned here.

One is the exploding growth in personal, remote, mobile communications capability provided in part through space networks. International mobile satellite communication has been principally limited in the past decade to INMARSAT, a large international consortium. The equipment has typically been large and suitable only for large mobile platforms such as ships and large aircraft. Recent market developments, matched with new technologies, have inspired the global offering of personal satellite communications applicable to a broad range of applications and users, including military. The potential size of the commercial market for such communications services coupled with competitive pressures will undoubtedly drive pricing down to levels that many foreign militaries can afford.

A consequence of growing satellite communications capacity and market demand is the increasing global competition for limited spatial and frequency spectrum resources. At geosynchronous altitudes, communications satellites are spaced apart to preclude interference with adjacent satellites. Some regions of the geosynchronous belt are saturated and diplomatic conflicts have resulted from competition for orbital slots. The frequency spectrum available for satellite communications is finite and must be allocated among the many users. This has driven the development of frequency reuse technologies to permit higher capacity within that finite spectrum resource while minimizing interference. The result is that more robust, less vulnerable communication links are becoming available.

The interesting consequence of the commercial markets' push for more efficient utilization of spectrum resources is that an increasingly dense and complex traffic environment will result. Through such concepts as packet-switched networks and agile beam forming antennas it will be difficult to identify, characterize, exploit or degrade specific users' communication links. Tighter spot beams, smaller, mobile terminals, and inherently more jam-resistant spread spectrum waveforms are already making commercial satellite communications less vulnerable. A virtual sanctuary may, in fact, be created for adversarial communications.

5.3.4.4 Remote Sensing and Intelligence

Remote sensing from space is an application that has been exploited in both the civil and military sectors for many years. There has been a slow, but steady growth in both sectors to provide increased resolution imagery. Low resolution imagery (30 m GSD) has been widely available from the Landsat program for many years as well as from Soviet earth resources programs. Even Landsat's combination of low resolution and infrequent revisit provides opponents with visibility into theater level troop movements (brigade level and higher), particularly with its multiple spectral bands. For example, General Schwarzkopf's famous "Hail Mary" flanking maneuver in the Gulf War was visible in a timely way in freely available Landsat imagery.

During the last decade several new international programs were launched to provide low and medium resolution imagery; primarily for earth resources purposes. For example, India started their IRS program in 1991 producing multispectral 36 m GSD imagery and the French SPOT program has provided 10 m GSD resolution since 1986. There are now several more sophisticated follow-ons to those programs as well as a new emerging international industry that proposes to provide high resolution imagery on the order of 1 m GSD within the next couple of years. As multispectral imagery of similar quality becomes more widely available,

camouflage, concealment, and deception will become more difficult. As multiple commercial sources become available, revisit opportunities will increase and responsiveness will improve. As commercial Geographic Information Systems software becomes more widely available and competitive, fusion of multiple source information will be commonplace and easy. All such capability being actively marketed by the international commercial sector.

International remote sensing programs are not limited to visible and infrared wavelengths. JERS, ERS and ALMAZ are three synthetic aperture radar programs that have flown or are currently flying which provide worldwide commercial access to synthetic aperture radar imagery. As the all-weather, day-night imaging capability of radar becomes more widely appreciated and the resolution provided by commercial systems improved, it is expected that space-based radar products will become an important adjunct to visible wavelength imagery in foreign militaries.

With the global availability of satellite imagery available from numerous sources there is clearly a broad, increasing awareness of space-based imagery applications. The utility of once classified military imagery systems is seen in the recently released US reconnaissance photographs and those on sale from similar Russian reconnaissance programs. Again, the Gulf War probably provided the single most important boost to the emerging commercial satellite imagery industry. The success of the French SPOT satellite program in providing high quality, reliable imagery services to coalition forces was a lesson many took home following the end of the conflict. For example, SPOT now actively markets to the world the broad military support utility of their imagery from reconnaissance to target characterization and infiltration route planning, among other things.

There have been several comprehensive studies performed recently on the impact of widely available satellite imagery. Virtually all of those studies conclude that imagery from commercial sources as well as military programs will be available to the US, its allies and its adversaries. If the imagery is not available from the US, there will be sufficient supply available from foreign sources to accommodate many foreign military requirements. Performance issues such as timeliness, coverage area, downlink options and resolution will be dealt with by the competitive forces in the commercial market place. More foreign militaries are expected to take advantage of commercially supplied imagery as competitive forces result in lower prices and more useful products.

5.3.4.5 Early Warning

The slow, but steady proliferation of ballistic missile technology and programs has raised interest in several countries in the ability to detect of missile attacks. Currently only the US and Russia possess space-borne missile early warning systems, but other countries are anticipated over the next couple of decades to seek similar capability. This may stimulated by the desire to be less dependent upon US supplied and controlled data such as during the Gulf War. The Western European Union, for example, has expressed interest in obtaining the capability to detect missile launches from the Middle East and North Africa aimed at Europe. France, in particular, continues to show much interest in having such capability. The high costs associated with such systems will probably drive most serious players into cooperative arrangements rather than outright purchase.

5.3.4.6 Space Forces Support

The space forces support function, addresses among other things the command and control of domestic military space elements and surveillance of foreign space programs. It is an area of increasing world-wide capability as commercial space systems become owned and operated by a number of countries. Some countries, like France, have developed global command, control and tracking networks allowing them to communicate with their satellites over broad areas for command and data downlink purposes. Such a capability provides flexibility to support military operations over broad areas as well.

As the commercial sector increases its participation in space on a global level, it will probably find that it requires global control capability. The high costs of large, geographically distributed ground segment networks will probably preclude most countries from developing them on their own. More likely will be coalitions and joint ventures to share costs. Or, with the spread of global interconnectivity (via space and terrestrial links) and such technologies as autonomous spacecraft navigation and control, new paradigms of global space command and control may result.

The technology and concept of operations are fairly common throughout the international arena thus providing easy insight into satellite operations by those interested. This, of course, helps to provide the understanding necessary by those adversaries that might choose to develop space countermeasures.

Space object surveillance and identification (SOSI) capabilities are prolific throughout the world. In addition to those countries possessing their own dedicated infrastructure of tracking radars and optical sites for SOSI, there is a growing capability within the amateur astronomy and similar non-government entities to perform SOSI. There are several studies that have explored the threat implications of such capability with respect to supporting various counterspace activities. The fact that such interest abounds worldwide, the ability to disseminate tracking data global via the Internet and the electronic and optical technologies are available to support such SOSI activities is further strong evidence of the international availability and pervasiveness of advanced space-related technology.

5.3.5 Implications for Space System Architects

OK, so what? Space technology has become pervasive globally, an increasing number of countries have embraced the utility of space for military operations and technology transfer is driven by a multitude of market factors; *this is not new news*. At this point the reader is reminded of the intent of this paper. It is to highlight for the authors of national space policy and the architects of future US national security space systems some important issues concerning the evolution of a space market environment of truly worldwide proportions. To that end, the following sequence of key conclusions is presented. This sequence is not in and of itself significant, but rather just a convenient means for stimulating discussion.

1. The diffusion of space technology and related applications worldwide will continue unabated between friends and foes alike.

2. This has lead to and will continue to foster a more pervasive global understanding and exploitation of the commercial and military utility of space.

3. Aiding in this process is a maturing commercial sector which provides services via space and which has the ability to respond more quickly to changes in market demand and profitability than traditional military space programs.

4. The industrial infrastructure supporting this international commercial sector is starting to put more emphasis on providing more commercial capacity and capability on orbit rather than supporting similar dedicated military space systems.

5. The increasingly complex business and financial interrelationships seen throughout the global markets will continue to incorporate space-supported services into multinational enterprises while they foster the perspective that space is nothing more than a means to a business end.

6. These complex interrelationships will pose significant challenges during times of crisis and conflict when the parties involved may be inextricably linked together in a *defacto* international space architecture.

7. There will be increasing opportunities for foreign warfighters to obtain support from the international commercial space services sector as well as from new, dedicated foreign military space capabilities.

8. There will be new players and their relationships to US sovereign interests may not be singular and stable over the planning horizons currently under consideration.

9. The potential is increasing for all international space systems to become targets as reliance on space services increases and enabling technology for counterspace activities becomes more widely available.

What does this mean for the policy makers and space architects? It means that their consideration of the future must not only acknowledge the internationalization of space as postulated here, but also to seek to exploit the opportunities and appropriately respond to the various implied threats.

This paper concludes here not with specific prescriptions, but with some suggested guidelines for conducting the planning activities.

1. Constantly monitor the global development and utilization of space technology and directly inject the resulting intelligence into the policy and architectural functions.

2. Establish a link between the development of space policy (e.g., export control, regulatory controls, spectrum allocation) and the development of strategies for implementation of national space program objectives.

3. Carefully consider the near and long-term consequences of US and foreign institutional barriers to US industry participation in international space technology and services markets.

4. Exploit through international cooperative arrangements opportunities to influence space support to the warfighters; foreign and domestic.

5. Seek up front to understand and accommodate the ramifications and threats posed by reliance on complex international (and domestic) institutional relationships providing

critical national security space services.

6. Establish metrics and definitions for measuring and characterizing US superiority in national security space vis-à-vis that of the rest of the world.

The internationalization of space provides both opportunities and risks to US global superiority in space. The risks far outweigh the opportunities unless actions are taken to truly exploit the opportunities to mitigate or eliminate the risks.

5.4 Survivability of Space Systems

Gregory Canavan and Betsy Pimentel

5.4.1 Introduction

The survivability of space systems has been a concern for several decades. It might be expected that the end of the cold war could reduce these concerns; however, the changing international order and the diffusion of capable new technologies could make it even more of a concern in the coming decades. During the Cold War, strategic and intelligence satellites were essential in maintaining the balance, so both sides were reluctant to overtly interfere with the space assets of the other lest such actions escalate unpredictably. In that environment, modest augmentation of propulsion and hardening appeared adequate for perceived threats. Some satellites such as those for Strategic Defense and MILSATCOM aspired to higher levels of survivability, but they were the exceptions rather than the rule. Moreover, their survivability measures were only partially implemented, and are largely inappropriate for the emerging threats discussed below.

In the coming decades, there will continue to be a spectrum of threats reaching from electromagnetic interference and jamming to material or laser attacks. The former will remain important and measures to deal with them must continue to be developed. They are not, however, discussed extensively here, for two reasons. The first is that radio frequency interference is likely to remain an area of active probing between the major powers, and it is a very technology intensive field. In the process of developing techniques for remaining competitive with each other in this area, the major powers. should develop technologies that should keep them far ahead of second or third world powers. Thus, rather than looking back to the threats of the past or examining the incremental development of conventional electromagnetic threats, the material below looks ahead to the less understood challenges of next few decades.

These new threats are, for lack of a standard nomenclature, characterized broadly as interceptors and lasers. Interceptors are guided or self-guiding rockets with kill package payloads that will generally be nonnuclear. Such interceptors have been in development for decades. They should gain significant additional capability over the next few decades due to the diffusion of the technologies developed in the last decade for missile defense. Lasers are directed energy weapons that produce lethal beams of light. Lasers are of international interest for fusion, industrial, and research applications, which has lead to their worldwide availability. Interceptors and lasers are first discussed separately and then compared to assess their relative maturity and the difficulty of developing countermeasures to one or both of them.

5.4.2 Interceptors

Interceptor technology was given considerable impetus by missile defense programs of last decade, which improved the performance and efficiency of rockets, the sensitivity of homing focal planes, the accuracy of hit to kill packages, and the range, sensitivity, and portability of cueing and auxiliary sensors. Quite efficient rockets and kill packages have now been developed and tested through the efforts of a large number of laboratories and contractors. In the current funding situation, those technologies could be more widely available without too much delay. That assessment also holds for radars and infrared sensors, which also have a wide range of legitimate international commercial applications. Any rocket with theater or international

capability or interceptor with adequate sensors to intercept intercontinental, regional, or theater missile will also have some capability against satellites. A theater missile with a 1,000 km range on an optimal trajectory with a 250 km apogee needs a burnout velocity of ≈ 3 km/s. Fired straight up, it should reach an altitude of ≈ 500 km, which would give it significant coverage against satellites in low Earth orbit (LEO). Later, with improvements in boosters, sensor, and guidance, such interceptors could threaten satellites in medium Earth orbit (MEO) and later those in geo-synchronous Earth orbit (GEO).

A key element of an interceptor-based system is its search or cueing sensor. Such sensors have shown recent progress in terms of technologies that are capable of dissemination. It should be possible to cue interceptors with individual or internetted radars of the quality likely to be in commerce. It should also be possible to cue interceptors from repeated observations over many orbits of satellites that maneuver little. Some satellite signature reduction is possible, but it is difficult for satellites that are observed over long periods of time from many different angles. For satellites that do maneuver, visible or IR telescopic search or passive occultation could suffice for detection and track. In addition to the significant progress in those areas made in recent years by the DoD, the university astronomical community has made significant advances and adaptations of these technologies, which could widely disseminate search technologies with significant capability against even objects with significantly reduced signatures. Long, lightweight tethers can be used to connect decoys, spares or other mass to an active spacecraft. The resulting ensemble would function as a survivability aid, which could degrade some ASAT systems, particularly those of third world nations or rogue groups. This concept is described further in the classified annex.

The rest of the intercept would be much like that for missile defense, for which these technologies were intended. In particular, the handover to onboard sensors for hit to kill would follow the pattern of Strategic Defense, for which these on board homing sensors are developed. The key technologies are now widely available, because they have a range of uses. Both the early PtSi and the improved InSb mid-wavelength infrared focal planes have commercial as well as astronomical applications, and blown down long-wavelength infrared focal planes that are fully capable of intercepts of cold targets are available from commercial sources. Even the lidars needed for accurate ranging in the end game are now available from a number of laboratory and commercial sources.

The availability of rockets, search, and homing sensors do not appear to be a problem for the attacker. The microprocessors required to control the intercepts are available in any modern personal computer. And the algorithms and programming required to do so are open, available, and modest. The main problem would be the expense and difficulty of integrating them. The cueing sensors might cost ≈ \$10M; facilities and manpower might add a like amount, for total fixed costs of \$20-30M. Current theater rockets cost on the order of \$0.1M; improved rockets for this purpose might cost between that and \$1M. The on-board sensors might add another \$1M, for total variable costs of \$2-3M per engagement. If this facility launched 10 interceptors, its fixed and variable costs would be about equal and the total cost per launch would be about \$4-6M/interceptor. Such an interceptor would have a cost effectiveness ratio of about \$1B/\$5M = 200:1 against a \$1B satellite. And given the role that such large, capable satellites play in current assessments of developments in remote theaters, the value of negating them could be much larger than just the numerical value of this cost effectiveness ratio.

As to the difficulty of integration, search sensors of this quality are routinely manned by third world personnel; similar rockets were used effectively by poorly trained personnel in the Gulf War; the launch facilities are standard; the on-board sensors and electronics could be maintained by typical electronic technicians; and the programming is at the university undergraduate level. Thus, availability of components, cost, and integration do not appear to be a significant hurdle to the development of the level of capability discussed above.

The interceptors discussed above should be able to detect, track, and hit non-maneuvering targets. And it is unlikely that a large, flimsy satellite could out maneuver an interceptor designed to intercept theater missiles capable of executing 5-10 g maneuvers in the end game. If the interceptor does hit such a satellite, the collision would probably be fatal to the satellite. It is just about possible to shield a satellite against objects with an areal density, i.e., density times length, of 0.1 to 1 g/cm^2, and these interceptors could have areal densities 100 to 1,000 times that. Given penetration, the probability of hitting and destroying a mission-critical system is also high. Thus, interceptors based on the current levels of technology should have significant margin for the destruction of non-maneuvering or even maneuvering satellites. Against such a threat, satellites must be able to avoid being hit at all, or they cannot be considered survivable.

A brief word is in order on self defense, which is often invoked as a possible means of improving survivability. In its simplest form, the satellite, when attacked, would send a small rocket ahead to hit the attacker. But the attacking kill package could detect its release, and send out some decoys that could confuse and negate the self defense missile. Thus, the assessment of the effectiveness of self defense hinges on the relative masses of the self-defense rocket and the decoys. The following section discusses that comparison and finds self defense to be of marginal value to the satellite.

5.4.3 Decoys

For satellites with limited maneuver capability, an obvious countermeasure to kinetic interceptors is the release of decoys when under attack. That both increases the number of potential targets the interceptor has to consider and forces it to include more sophisticated sensors for their discrimination. Against entry-level interceptor with unitary payloads, the deployment of decoys need not be stressing. The decoys would only need to remain credible during last few minutes of approach, when they were closest to the interceptor and most susceptible to examination by its sensors. Hence, the decoys could ideally be quite light—possibly inflatable. They would primarily need to roughly match the satellite's overall emissivity-area, although in time attention should also be paid to the visible and infrared.

Deploying even simple decoys takes some mass. In strategic defense studies it was often found that an adequate thermal midcourse decoy for a 300 kg reentry vehicle (RV) could weigh about 1 to 10% as much, or ≈ 3 to 30 kg. An example shows the difficulty involved in achieving adequate leverage. Ten decoys would reduce the probability of the satellite being killed to ≈ 10%, if they worked perfectly. But even at 10 kg per decoy, the low end of the range above, the expected mass loss for a 1 ton satellite that is attacked by a single weapon is ≈ 10% probability of destruction x 1 ton lost if destroyed + 10 decoys x 10 kg/decoy ≈ 200 kg. That is much less than the 1 ton loss it would surely experience if the decoys were not deployed, but it is still greater than the ≈ 100 kg kill package mass of a near-term interceptor. Moreover, the satellite is in orbit while the attacker is on a sounding trajectory, so there is another factor of about 4 in

favor of the attacker. Thus, overall this engagement factors the attacker by about a factor of $4 \times 200/100 = 8:1$.

Increasing the number of decoys would not be of value. 20 decoys would give a loss of ≈ 5% probability destruction x 1 ton loss + 20 decoys x 10 kg/decoy ≈ 250 kg. Reducing the decoy's mass below 1% does not appear credible. Reducing the satellite's mass does have some value. A 100 kg satellite with 10 decoys would have an expected loss of ≈ 10% probability of destruction x 100 kg loss + 10 decoys x 1 kg/decoy ≈ 20 kg, which gives an overall exchange ratio on the order of unity.

It is useful to codify these calculations of the exchange ratio, E, which is the ratio of the masses expended by the attacker to that extended by the satellite. The mass expended by the attacker is P, the interceptor payload mass. The mass expended by the satellite is $\approx M/n + nC$, where M is the satellite mass, n is the number of decoys, and C is the mass of a decoy. Thus, the exchange ratio is $E = kP/(M/n + nC)$, where $k \approx 1/4$ is the attacker's advantage due to his sub orbital trajectory. While the attacker's mass is fixed, the defender's can be minimized by the choice $n = \sqrt{(M/C)}$. For $C = fM$, $n = 1/\sqrt{f}$. For f = 1%, the optimum number of decoys is 10, as shown in the examples above. For that choice the defender's expected mass loss is $2\sqrt{(MC)} = 2M\sqrt{f}$, and the exchange ratio is $kP/2M\sqrt{f}$. Thus, the principal means of increasing survivability are decreasing mass and f. A 100 kg satellite with 1% decoys roughly breaks even. A 30 kg satellite with 0.1% decoys would have about and order of magnitude margin.

While the examples and derivations above indicate that small satellites could have some effectiveness against current interceptor threats, it should not be forgotten that it could also be possible to significantly reduce the mass of the interceptor kill package, and perhaps to improve their discrimination capability in the process. It is not clear that decoys is a winning game, it is only clear that it is more viable than the survivability of large satellites, which scale in the opposite direction and leave much of a constellation's essential capability concentrated in a single satellite.

5.4.4 Fragment Warheads

Fragment warheads add some complications to the above discussion that are worth noting briefly. The first is the simplification of intercepts with fragment warheads. The discussion above assumed that adequate hit to kill technology was available. That seems a reasonable assumption, but it is not essential. Even in hit to kill systems it is conventional to use lethality enhancers in terms of pellets or wire meshes extending some distance out from the interceptor to increase its geometric coverage. Such devices would also be applicable in attacks on satellites. Moreover, since the satellites can maneuver less and are more vulnerable, the nets could be spread much more widely. Indeed, a 100 kg kill package could spread centimeter pellets over an area 100 m across, which could eliminate all of the decoys and satellites in that area.

This leads to the second point: fragment warheads make this attack a game. Spreading the threat cloud widely covers more area, but might permit the satellite to slip through. Thus, the defender must optimally choose the thickness of the shielding on the satellite and the attacker must optimally choose the size of the threat cloud separately but in concert. The result is a penalty for survival that is roughly proportional to $MP^{1/5}/L^{2/5}$, where M and P are as above and L is the warning distance the satellite has to maneuver. For a 100 kg kill package and L = 10 km,

this penalty would only be few percent of the satellite mass-divided about 60% for maneuver and 40% for hardening. If the attacker could reduce the distance to maneuver to a fraction of a kilometer, the penalty would increase to a significant fraction of the mass of the satellite.

5.4.5 Attrition

Attrition attacks are variant on the discussion above, which assumed that the attacker needed to negate the satellite on some given pass overhead. If the attack could be made at a time of the attacker's choosing, that adds an additional dimension to the defense's problem. Some measures—particularly maneuver and decoys—are most effective if initiated at the first sign of launch. That makes those defenses susceptible to false alarms. If the attacker made a convincing show, but did not launch the interceptor, the satellite could be misled into expending mass for fuel and decoys as if it were attacked. While it could afford a few such maneuvers, in time its fuel and decoys would be exhausted, which would defeat its mission. Moreover, as it approached the end of its reserves, it would be in an increasingly vulnerable and unstable mode. Since the decoy attacks could be simple, cheap, and sub-orbital, the economics of such feints should strongly favor the attacker.

Viewed from the perspective of the defense, the need for a possibly large number of attacks before exhaustion was reached could allow the defender to interdict the interceptor launch sites by other or on-board means, if available. In following this approach, however, it would still be best if the satellites had some degree of survivability on each pass so that the attacker saw an incentive for attacking them deceptively over time rather than just destroying them on their first pass.

5.4.6 Space Mines

Space mines are the limit of coorbiting antisatellites. They are mentioned here for completeness because they presented a nagging problem in the last decade that was never satisfactorily resolved. They are small satellites that are launched on optimal trajectories to gradually approach for rendezvous with large satellites, which they then track through their large signatures. They remain in trail until they are told to destroy themselves, and the target satellite in the process. Because they are much smaller than the host satellite and need only sensors adequate to track it from short range, they can be cheap and efficient. Having them nearby would effectively negate the host satellite's mission. It will probably not be possible to know whether the mine is threatening. It may not be possible to know who launched it. It is not clear that such mines would be detectable from the ground.

Here, the interest in mines is that they are a form of attack that could operate with cueing sensors comparable to those for direct ascent kinetic energy interceptors. Moreover, they are the type of small, simple payload that a country might just be able to put into space when they first gain an independent space launch capability. If they wished to quickly gain a role as a significant player in space, mines would be a logical vehicle for staking that claim.

Mines are quite awkward to negate. They are hard to detect from the ground—even from space, unless all satellites are provided capable search sensors. It is not possible to use normal maneuvers to loose them, as their smaller size and simpler mission enables them to follow maneuvers closely. Eliminating them would appear to require a search set and self-defense

means on each satellite or a roving inspection capability. Either would represent a significant cost and loss of flexibility. If it could not be assured that the mines were nonnuclear, these means of disinfectant might not be viable at all.

5.4.7 Overall Assessment of Interceptors

Kinetic kill interceptors have been a significant concern for several decades. While the previous systems were of limited capability, the development and diffusion of improved cueing, missile, homing, and lethality enhancement over the last decade has significantly extended the capability available to potential attackers for modest investment. Given good information on trajectories, the combinations of technologies in commerce should be capable of hitting most satellites. Give that they did, hardening would appear to be of marginal value at best. Very light and capable decoys could provide some margin, but only for small, light, and cheap satellites. For large satellites, the only defensive measures with much leverage would appear to be the denial of trajectory information through signature reduction, deception, the use of other objects for cover, etc. While these measures appear difficult, the alternative would be moving these satellites out of low Earth orbit.

5.4.8 Lasers

Lasers differ in that they both move and track targets with the speed of light, which negates the effectiveness of target maneuver. Moreover, they send up only photons, which can enter space with little penalty. That tends to give the attacker a great mass and cost advantage. There are two pain types of high power lasers. They are described separately here, because they have distinctly different modes of interaction, which lead to significantly different effects and countermeasures. Continuous wave (CW) lasers run continuously for many seconds. They interact by depositing heat on their targets, which they kill by cutting structural members or melting internal components. Pulsed lasers deliver their energy in short bursts of energy, typically milliseconds to microseconds long. Its deposition vaporizes and blows off material. The recoil produces impulse on the target, which can blow holes in surfaces and break structural elements. Thus, the kill mechanisms are closer to those of kinetic energy interceptors.

Lasers have not been a serious threat to date because the lasers have been too large and expensive and because their beams have been spread out widely by the atmosphere. Recent technical developments have removed both of those constraints. Pulsed lasers can now be scaled to the MJ level, which is adequate for lethal applications, for a few $M with several different technologies. Even more important than the advances in laser technology are the advances in active optics. An uncorrected beam propagating upward through the atmosphere develops a spread of about 2 arcsec (10 microradian), which is set by the atmospheric "secing" at good sites. In propagating to a satellite to a satellite at a range of 1,000 km, the beam then spreads to a diameter of $\approx 10^{-5}$ rad x 10^{6} m $\approx$ 10 m. For a MW laser, that would produce a power density of $\approx$ 10 kW/m^2, which is only a few times the flux from sunlight. It is possible to shield against such fluxes simply and passively. Such power levels do not represent a serious threat. It is possible to produce much higher power lasers, but nonlinear effects in propagation through the atmosphere further distort the beam and actually reduce the received power. There are special problems with sensors, but they can be protected or covered. Thus, large lasers with uncorrected beams do not appear to pose a serious threat to even lightly hardened satellites.

The situation is quite different for corrected beams. Active optical systems sense the density distortions that cause phase errors and cancel them with conjugate motions of deformable mirrors.. That restores the diffraction limited beam divergence of $\lambda/D \approx 10^{-6}$ m /1 m $\approx 10^{-6}$ rad ($\approx$ 0.2 arcsec). Thus, the beam diameter at 1,000 km is $\approx 10^{-6}$ rad x 10^{6} m $\approx$ 1 m, so the power density is $\approx$ MW/m^2, which cannot be countermeasured passively. Such fluxes would kill in a few seconds. The energy density from a MJ pulse is $\approx$ MJ/m^2, which is also far above the threshold for enhanced coupling and shock production. It would be difficult to shield against the pulsed laser, which would deliver energy at a rate of about 10^{12} W/m^2—about a billion suns. Such fluences would kill in microseconds.

The technical requirement for producing such a weapon are not great. The main need is an active mirror with about as many corrector elements across it as there are atmospheric coherence lengths across the primary aperture. For a 1 m aperture and 10 cm coherence (good seeing), that would require a mirror with $\approx$ (1 m / 10 cm)^2 $\approx$ 100 actuators. It would also require a low power laser for atmospheric sensing. Such mirrors and probe lasers are being provided to U.S. and foreign astronomers for legitimate scientific projects. The astronomical community has already adapted and is making improvements to both key technologies. An awkward aspect of pulsed lasers is that they could be very difficult to find. Even using current technology, the active region of a MJ laser could be on the order of 4-5 m in diameter, and the energy storage and optics region might be only a few times larger. Thus, a MJ laser could fit in a garage-sized building, whose only distinguishing features could be a sliding roof panel and a modest power supply. This lack of large, visible signatures could make it difficult to interdict the laser should other defensive means fail.

Corrected lasers track without penalty, so they negate the effectiveness of maneuver. Decoys are also ineffective against lasers, since laser pulses could be generated for $\approx$ \$1,000 per shot, which is much less than the launch cost of decoys weighing as little as a few kg. The laser should have an adequate shot rate and engagement time to irradiate many decoys and watch them deflate, leaving the target in view. It might be possible to shield against certain levels of attack by CW lasers by exhausting hydrogen, but the amounts required are very large and could be quickly exhausted. Against pulsed lasers, it should be possible to use shock shields or sacrificial layers to decouple energy deposition from the surface of the satellite. That could reduce material removal, so attrition would be less by one measure. However, even with decoupling, significant shocks would be produced, which could break reinforced mechanical structures. Pulsed lasers produce typical coupling coefficients of C $\approx$ 10 dyne-sec/J, so a MJ pulse would produce $\approx$ 10 dyne-sec/J x MJ $\approx$ 10 Mdyne-sec, which would produce a relative velocity of $\approx$ 100 m/s between irradiated and non irradiated parts of a satellite. That would cause the irradiated material to blow in and turn into fragments, which would be difficult to accommodate.

Even if it was possible to block bulk damage of the satellite, it would still be necessary to guard against sensor kill. Focal planes are particularly vulnerable. In a short pulse, a fluence of 100 J/cm^2 might damage a single detector. That is a significant flux, but an optical system with a 10 cm aperture would magnify the incident radiation by a factor of $\approx 10^8$, so an input fluence of $\approx 10^{-6}$ J/cm^2 could damage focal plane. Moreover, with that much leverage, even the energy that blooms over onto adjacent detectors due to scattering in the optics could damage them too. Even if the transfer function of the optics was good enough to provide factor of 2 isolation for every additional detector separation, several hundred detectors could be affected. Such damage

would negate the primary mission of an imaging sensor. It would not be acceptable. Means to overcome it are needed. There are some ideas in the form of very fast acting shutters, which would detect the incident radiation and shut off before unacceptable levels of light were transmitted. Such protection might be possible for CW lasers, for which the damage accumulates over many seconds. It is much more difficult against pulsed lasers, which would require isolation to build up from low levels to a factor of 10^6 or more rejection in microseconds. That should be possible with semiconductor electro-optical switches, but is not available.

The comments above have concentrated on lasers for specificity, but they apply to other related electromagnetic threats such as microwave weapons as lesser included threats. Microwave weapons have undisturbed propagation, so active correction is not an issue. However, the do require arrays that are larger by the ratio of their wavelength—about a factor of a million than lasers—to achieve the same spot size and flux on target. That translates into football field sized transmitters. Microwave weapons also have the advantage of coupling in through various electrical cracks in devices, which can give efficient coupling. Conversely, those leaks can be shielded against through known, developed means. Overall, microwave weapons have many of the advantages of lasers coupled with very large, visible, and expensive transmitters. Other such concepts such as electron and particle beams are too immature by comparison to even be assessed on the same footing.

Overall, laser threats appear to be significant, near term, and difficult to address. The key technologies needed to make lasers very large and effective have been placed in civil scientific, commercial, and international hands. It would be difficult to recall them. Lasers make maneuver and decoys ineffective, and they make hardening very difficult. Satellites would be unable to make more than a few passes over large lasers before exhausting their countermeasures. Thus, in that time some other means of dealing with the transmitter must be sought. Unfortunately, given the small size and limited observables of even large pulsed lasers, it is not clear that there would be a proper basis for effective interdiction.

5.4.9 Distributed Systems

A number of observations above have indicated the advantages of distributed systems in promoting survivability. This section collects those arguments together. Distributed constellations have advantages in scaling and performance that are discussed elsewhere. Their survivability is of particular interest here. It results from the distribution of the capability of the constellation about equally over each of its components. In such a configuration, the degradation of the capability of the constellation would be reduced only in proportion to the number of satellites lost. The flexible and proper interconnection of the rest could make the overall system intrinsically survivable. In most applications, the loss of one satellite would not even be felt for several days. Moreover, lost elements could be replaced quickly on demand with modest launchers. A somewhat different aspect of their scaling is the potential synergism with civil and commercial satellites, whose integration through add on sensors could increase the number of satellites in the constellation even further. A final point having to do with the defensive capability of distributed systems is that if the satellites were required to use space-based assets to achieve survivability of the constellation, distributed systems would distribute the needed defensive and offensive systems directly over the threats to themselves and others.

5.4.10 Space Control

There is a fundamental connection between the narrow technical issue of survivability and the overall policy of space control. Control of space requires that we have freedom of action to accomplish our objectives (military, civil or commercial) and the ability to deny similar freedom of action to potential adversaries. The 1989 National Space Policy reaffirmed U.S. goals in space of deterring or defending against enemy attack; assuring that hostile forces cannot prevent our use of space; negating hostile space systems; and enhancing United States and Allied operations. For the DoD to maintain enduring space systems implies an integrated combination of antisatellite, survivability and surveillance. The Air Force has developed this into a doctrine including surveillance, protection, prevention, and negation.

This discussion requires the Air Force to be able to remain in and move freely and forcefully in space to do essential missions. To do that, Air Force systems must be survivable. According to the discussion above, that is not likely to be the case over the coming decades. Moreover, space control also requires the Air Force to be able to deny such free access to hostile powers. By the converse of the analysis above, logically, the Air Force should be developing advanced interceptors and lasers capable of denying access. It is not. Thus, both in terms of the positive survivability the Air Force should be developing to perform specified functions and in terms of the offensive anti-survivability capability it should be developing to exploit weaknesses of hostile powers, there is a growing gap between the positive policy and doctrinal statements that should guide development and the actual and likely course of events.

5.4.11 Summary

Satellites previously received a free ride, which was an exception to the usual military rule of seeking and exploiting the opponent's weaknesses. That resulted from satellites unique value in maintaining a stabilizing flow of information during the cold war. In the post cold war era, these arguments are less compelling, and the new threats from lesser nations, which are not so inhibited and which now have access to comparable levels of technology, are gaining in importance. Interference with launch, command signals, and communication will continue, but the new element is the threat from the advanced technologies disseminated by the missile defense activities of last decade.

The primary threats are advanced interceptors and lasers. Interceptors have benefited from development and dissemination of the needed cueing sensors, rockets, homing sensors, and kill packages. Non-maneuvering satellites would not survive against them; even maneuvering satellites would be marginal. For survivability, satellites would need good, light decoys; even then exchange ratios are only favorable for small satellites. Exchange ratios are also marginal against fragmenting warheads, which largely eliminate effectiveness of decoys. Attrition attacks are possible even at lower levels of technology. Space mines that efficiently co-orbit with the prey satellite are elegant, simple, and anonymous. They could be constructed with a modest level of technology. They were a nuisance threat of the last decade that could be just within the grasp of new space powers in the next decade. In the most favorable situation, satellites could use countermeasures to make some number of passes over the threat, which would give some time for it to be interdicted by other means. Overall, advanced interceptors appear to be a threat that could be deployed within the next decade on the basis of released technology.

Lasers track and kill at the speed of light, which negates decoys and maneuver. Large energies are now available cheaply. Active optics, which are now widely available, makes the transmission of near perfect beams to space possible. The fluxes and fluences that can be delivered to low Earth orbit by such lasers are apparently too high to shield against. Such lasers could exhaust a satellite's countermeasures in single overhead pass. The issue of sensor kill looks somewhat worse. The only straightforward countermeasure is a large extension of electro-optical isolation technology. Thus, lasers are an awkward threat. They appear to be a low priced system with few observables—either for development or use. The timelines for their appearance could be about the same as that for interceptor technology.

Over next few decades satellites will probably become more valuable in assessing a more complicated world situation, but at the same time they will probably be stripped of their historical political protection. They will need active measures to survive and function. The only physical measures developed thus far are modest levels of hardening and maneuver. It does not appear possible to harden against either the kinetic energy interceptors or the energy delivery rates possible with lasers. It does not appear feasible to use maneuver alone against interceptors or to use it at all against lasers. Decoys play a role, but they are not particularly effective for large satellites, fragments, or attrition attacks and they are completely ineffective against lasers. Thus, a new generation of countermeasures appear to be needed. None have been suggested.

Against interceptors, large satellites may be able to use decoys and maneuver to survive long enough for the interdiction of the launchers. Small satellites can use decoys more effectively, and can be lost without catastrophically degrading the performance of the whole system. Against lasers, either would have to use enough shielding to avoid bulk damage, enough isolation to avoid sensor damage, and enough auxiliary assets to locate the transmitter for interdiction by on- or off-board means.

It is difficult to say which of these threats is the more difficult. Against interceptors, satellites need decoys and maneuver; and shielding is ineffective. Against lasers, satellites need shielding and protection; and maneuver and decoys are ineffective. For effectiveness against likely threats that combine the two, satellites would appear to need protection against both sets of attacks—and to need them in about a decade. They would also need the means to locate and interdict launchers or transmitters with quite low observables in less than a day. Two positive notes are that it is still possible that effective protection might be implemented with a fraction of a satellite's mass, and that the means of achieving both survivability and interdiction might develop from attempts to provide global real-time surveillance, communications, and strike through distributed systems.

5.5 Distributed Space Systems

Gregory Canavan, David Thompson, and Ivan Bekey

5.5.1 Introduction

Rapid progress in a number of new technologies—computers, sensors, materials, etc.—have made large constellations of satellites with good sensors affordable. This paper explores the new applications that these developments make possible and the technologies that are available to support them. Alternative architectures involve distributed systems of constellations with many satellites, each of which has modest sensor and communication capability, whose integration gives the whole constellation global, real-time coverage. Such constellations can also have advantages in scaling, performance, cost, and survivability. The next section discusses the essential features of their scaling that determine when they do. The following section describes the new defensive applications such scaling makes possible. It is followed by a discussion of the appropriate sensors, their status, and the platforms on which they might be mounted. The paper concludes with rough estimates of the timelines and resources for development and a summary of the prospects for their integration with other defense, civil, and commercial activities.

5.5.2 Alternative Architecture System Scaling

The advantages of alternative architectures of distributed systems result from the reduced ranges from the satellites to their targets and to each other. This scaling is discussed in detail in the Appendix; the principal results are discussed and simply illustrated here.

Passive, scanning, sensors of a given resolution require a sensor of diameter, D, which is proportional to the range to its target, r. Thus, for a given level of technology, the sensor's volume increases roughly as the cube of its range, and its cost increases proportionally. If the sensor is responsible for targets out to a cross-track swath W, the number of satellites, N, required to achieve a revisit time T, is inversely proportional to W and hence range. Thus, the total cost of the constellation, which is proportional to the product of the cost per sensor and the number of satellites, varies as the square of the range to the target. That means there is about a factor of 4 advantage for deploying twice the number of satellites at half the range.

More careful analysis shows that such satellites should be operated as low in altitude as possible with a swath about 1.5 times their altitude. There is some latitude about this optimum. Increasing T would decrease cost—at the price of less timely data. Degrading resolution would decrease cost—at the price of a disproportionate degradation of the value of the data. Increasing T or degrading resolution would be the final steps in cost reduction. These optimizations are insensitive to the costs for the focal planes and supporting computers, which are fixed. However, those costs are significant, and should be controlled, lest they upset the proper balancing of aperture and constellation size. At high resolution, aperture costs dominate those for focal planes and computation, although scanning sensors might require excessive array sizes and bandwidths for whole-Earth coverage.

Active sensors such as lidars, radars, and SARs offer less advantage for distribution. The product of their power, P, and aperture, A, generally scales as the fourth power of range, which suggests strong benefit for operating at small r. However, P and A can be optimized separately to minimize total cost, which is the sum of the costs for P and A. That is minimized by the choice

A proportional to P, which gives a power-aperture product PA proportional to the square of P, so that the cost per sensor only increases as the square of range. Active sensors should be deployed as low as possible; their cost has a shallow minimum at a swath twice the altitude. Thus, there is less of a penalty for operating active systems away from optimum separations. Active systems operate at about 30% greater range than passive systems because optimizing both P and A allows them to do so with less penalty in sensor cost.

Communication satellites have quite different scaling in distributed operation. While they would not normally be used in a scanning mode—apart from store and forward systems—their scaling in a scanning mode can be discussed simply. The key issue is the link margin between the satellites and ground stations. If the satellite has aperture area A, the power density at range r is proportional to PA and the signal received by an aperture A there is proportional to PA^2. Since P and A can be optimized separately, their cost is proportional to P, while PA^2 scales as the cube of P, so the cost per channel scales as $r^{2/3}$, for which the optimal range is large enough for Earth curvature to be important. Long-haul communications satellites do not distribute favorably.

An exception is the growing area of distributed communication directly from satellites to user handsets and pagers, for which the key link is from the handset to the satellite. That is limited by the power that is allowed and the antenna gain that will be tolerated. The former is set at $\approx$ 3 Watt by the FCC; the latter is dictated by customers, who do not care to point high-gain antennas at satellites. Thus, rather than the high gain of long-haul systems, personal handsets have little gain, so the received signal is proportional to A, the cost per satellite scales as r^2, and their scaling is much like that of the other active systems discussed above, i.e., their optimum swath is about twice their altitude, and the penalty for operating with wider swaths is modest.

Staring sensors must observe most of the surface of the Earth at all times, which changes the basis of constellation sizing from coverage within a given revisit time to complete coverage at all times. If each satellite is responsible for staring continuously at an area » W^2 below it, the number of satellites required is inversely proportional to W^2. If the cost per sensor scales as the cube of range, as above, the constellation cost scales as the cube of the range divided by the square of the W, which is minimized by reducing r to about the constellation altitude and operating at the minimum altitude possible. There, costs have a shallow minimum about a minimum at an optimal swath of about three times the constellation altitude. Thus, the advantage of operating staring, passive systems in a distributed mode is about equivalent to operating active systems in a scanning mode.

For other staring sensors, distributed operation is less advantageous. Active sensors costs scale as r^2, so their constellation cost scales as r^2/W^2, which does not favor operation at shorter ranges. Direct satellite communication from handsets scales as r^2, which also does not favor operation at shorter ranges, although distribution may be preferred for voice delay and engineering considerations. Long-haul communication systems scale as $r^{2/3}$, which favors operation at maximum range. Thus, whether or not distributed operation is appropriate for a given mission depends on the detailed scaling of the sensors proposed.

Space based kinetic energy systems scale quite differently. To reach their targets during the time T allowed by missile burnout, warning cycles, target movement, etc., kinetic energy systems' velocity, V, must be such that VT = r, where r is the distance to target. If complete coverage is required, the number of vehicles required is inversely proportional the square of

range or inversely proportional the square of VT. While T is determined by the application, V can be varied. However, higher V costs more in launch mass and volume. The optimization of kinetic energy systems is a tradeoff between the cost per interceptor and the number of interceptors. For a range of missions, the optimal velocity is on the order of 6 to 8 km/s, which with a roughly 4 kg kill package implies a 40-60 kg space vehicle. Such vehicles could arguably be produced for roughly \$1M each. Is so, with 100-200 s warning, a constellation of ≈ 1,000 systems for single coverage would cost about \$1B.

A distinguishing feature of kinetic energy systems, whether used for defensive or offensive purposes, is that they are distributed directly over the threat, which generally gives them the minimum response time possible. That has different impacts for defensive and offensive applications. For defensive applications, this very fast response time permits space-based systems to address missiles in boost, when they are most vulnerable and before they can deploy decoys or multiple munitions. For offensive applications, fast response would permit delivery of munitions in minutes rather than hours, which could be important in blocking or disrupting highly structured operations or attacks until other means could be brought to bear. In such applications, highly accurate delivery of \$1M munitions from space could be quite cost effective relative to other interim means of blocking such operations.

Related considerations. The sections above have discussed the advantages for distributed systems that follow directly from the scaling of their sensors and platforms. Other considerations arise from their low-altitude operation. An obvious one is the greater drag satellites experiences at lower orbits. Although satellites at 300 km altitude would experience an order of magnitude more drag than one at 500 km, with proper design and modest makeup propulsion, it should be possible to achieve lifetimes of 2-4 years. That possibility is not unique to small satellites; it could be used to advantage by large satellites as well. However, at present, only a few do.

Such lifetimes would be short compared to those of most current satellites, but not too short to be useful. Moreover, they are matched to doubling times of computer and focal plane technology. Thus, distributed satellites could be maintained in operation for a few years and then allowed to decay at about the point at which they became technologically obsolescent. Of course, these options for more rapid turnover of technology are not unique to small satellites either; they could be used to advantage by large satellites as well. However, to date, only small satellites have taken advantage of them.

A related issue is the large data rates and transmission bandwidths required for the scanning and staring sensors discussed above, which would far exceed the capacity of current flight computers and transmitters. However, the much larger on-board computers are now available could be used to compress the data from improved instruments into the available bandwiths. This is not an intrinsic advantage of distributed systems; however, they have been the quickest to introduce the current level of technology. This would appear to be an area in which both small and large satellites could benefit from more aggressive deployment.

Many applications require revisit times of minutes or hours, which in turn require constellations of 30-100 satellites. For such constellations to be affordable, the satellites in them must be small and inexpensive. A cost goal of \$1B for 30 satellites would give ≈ \$30M per satellite, which is far below industry standards. However, a number of commercial enterprises, such as Motorola's IRIDIUM are now in the process of producing such satellites in even greater

numbers with roughly those cost goals through industry factory line procedures. Those cost goals also imply a cost goal of ≈ $10M for the sensors for distributed systems, which is also stringent. But the individual Clementine sensors were built for significantly less than that, and current developments in visible and infrared focal planes for imaging systems indicate that such a goal is not unreasonable. The cost of active systems is not as well known, since they have had less development for space. But lidar, SAR, and radar sensors have each been developed extensively for special applications, and each is capable of efficient scaling to small payloads. Thus, they too could contribute from distributed systems.

Survivability is another key consideration, although all of the factors are not analyzed. Some points, however, are obvious. Since the capability of the constellation is distributed about equally over each of its components, their proper interconnection could make the system intrinsically more survivable, in that the loss of one element would not be catastrophic, and would not even be felt for several days. Moreover, elements that were lost could be replaced on demand by modest launchers. A related point is the potential synergism between distributed systems and civil and commercial applications. The small size of the sensors for distributed systems could make it possible to use them as add-on payloads to commercial and communication satellites, which would further increase the number of the satellites and further increase the survivability of their constellation. That complementarity would not be possible with the large sensors from unitary satellites.

5.5.3 Defense Applications

Defense applications for distributed constellations include missions ranging from missile warning to communications. Some are unique to distributed systems; others are shared with smaller constellations. This section primarily discusses the applications; the next section discusses the application of distributed systems to them and why it would or would not be effective. Some of the applications are shown in Fig. 1, which indicates the rough spatial resolution and temporal revisit time required for a number of defense missions, together with those for a few representative civil and commercial applications.

Defense applications generally lie to the lower left part of the figure, at demanding spatial and temporal resolutions. Missile warning and watching is at the lower corner. Technical assessments are along the left side, where the required spatial resolution is high but longer times may be available to achieve it. Global surveillance—and its component damage, chemical, and biological assessments—start on the lower border at revisit times of tens of minutes. Meteorological applications lie at the lower right, at modest spatial but demanding temporal resolutions. Agricultural, crop maturity, and disease applications lie to the upper right at modest space and time resolutions. Climate change studies lie at still lower space and time resolution. Civil applications have significant overlap with each other as well as with the traffic, disaster control, and some military applications—particularly at intermediate space and time resolutions.

Missile warning is a well established mission. Watching the missile's bus for decoys and weapons is just the most demanding form of it. The current system is based on radars and short wavelength infrared sensors on satellites at GEO altitudes. The satellites are capable, although based on decades-old technology, using linear arrays of detectors with large pixels to produce adequate signal to noise ratios that are adequate against large current strategic missiles. They now integrate the outputs of several satellites to obtain range information, which improves track

accuracy. They also have a useful capability against the much smaller signatures of theater missiles, against which their main weaknesses are the delays between revisits, which causes them to miss transient events and to take tens of seconds to give warnings and establish tracks.

In adding advanced detector arrays to improve detection, discrimination, and track, distributed systems are probably the preferred because of their ability to increase signal by decreasing altitude and decrease pixel size and detector count simultaneously by diving the search area between a number of sensors and satellites—so long as these improved focal planes could be introduced without giving up range information, which would be a step backwards in terms of tactical and strategic utility. The laser and radar rangers discussed below could provide that information for distributed systems. They progressed slowly for several decades, but have now reached about the right level of development. Staring systems should have modest but real advantages in this application when deployed at low altitudes and comparable fields of view.

Much of the pressure for a shift to distributed, staring systems comes from increased concern with theater threats. However, threats is single theaters might be addressed more cheaply by additional AWACS aircraft, which are individually expensive and redundant, but which do not encounter space-based systems' absenteeism, i.e., the geometrical fact that most of the constellation is somewhere else over the globe at any given time. For simultaneous threats in multiple theaters, absenteeism is automatically reduced and distributed space-based systems could become economically competitive due to their lower unit cost. Distributed space systems would also benefit from their survivability, which could be significantly greater than that of aircraft with active sensors that must continually radiate to be effective. In the longer term, distributed space-based radars for all-weather search, detection, and track would be a natural adjunct to other space-based sensors as well as to AWACs. With this combination, it should be possible to detect, track, perform threat assessment, and direct intercepts from space.

Several emerging applications require technology and systems closely related to that for missile warning. Distributed systems can use smaller pixels for better spatial and spectral resolution, which is difficult to achieve with large satellites at GEO. Such resolution could be valuable in detecting and tracking aircraft and cruise missiles, which are likely to become an increasing fraction of the threat in coming decades as ballistic missile defenses shift the threat to other delivery means. In this period, the U.S. could also face serious, competent competition for the control of space. In it, smaller, more numerous, non-GEO satellites would have distinct advantages. Hardening would be simpler. Maneuver would be less costly. Decoys and self-defense would be simpler and more efficient. And from the systems perspective, the loss of one satellite would be less damaging and easier to remedy. All of these defensive capabilities will be essential in protecting the satellites' long enough to perform their warning and assessment mission, which will become more important in this period.

Global surveillance will gain in importance as more countries gain access to modern weapons to press their grievances with neighbors and as weapons of mass destruction and their carriers proliferate to more theaters and countries. Current systems are capable of daily reconnaissance of small, fixed areas, but lack the prompt, synoptic coverage needed for assessing emerging threats, attacks, or occupations. Interim use of Landsat and Spot helped fill that lack in the Gulf War, but assets with prompt, global coverage dedicated to this task are needed. The characteristics of the needed systems have largely been defined in the section on scaling. The optimal solutions are generally distributed systems, because of the difficulty of producing the

required resolutions from high altitudes or long ranges. It appears feasible to produce appropriate constellations of either scanning sensors with resolutions of meters and revisit times of hours or staring sensors with finer resolution and near-instantaneous access to all points below. Each has significant advantages over current systems; scanning systems' advantages are particularly great for applications that admit their somewhat longer response times. The cameras, computers, compression, and transmission capabilities required appear to be within current capabilities; they have significant and useful commonalties with those for distributed missile warning.

An interesting extension of these concepts is the coupling of visible or infrared staring arrays with large-scale, on-board signal processing to perform moving target detection on board the satellite. The cameras are modest compared to current flight units; the computation rates are roughly what current flight computers can supply; and the resolution required is roughly what current mid-wavelength infrared focal planes can provide. Adequate algorithms are known and tested. Combining these elements would provide a capability to detect and track moving targets from orbit. If so, the satellite would only need to transmit the track—not the whole sequence of scenes—back to the ground for discrimination, which would make much more efficient use of target designation assets. Alternatively, if the satellite was equipped with a kinetic energy projectile, it or its neighbor might prosecute the attack itself.

Such surveillance systems could perform certain missions that are not addressed at all today, whose importance is increasing. One is the detection and track of mobile missile launchers and relocatable missiles, which move with impunity today during the long intervals between the known times of overhead observation. Frequent observations from distributed systems would largely remove the effectiveness such systems. The timely, selective dissemination of modest-resolution information from such distributed sensors could be a very effective means of maintaining prompt coordination of activities with allies.

Damage assessment concentrates on higher spatial resolution of limited areas that have just been attacked in order to evaluate whether the attack has achieved its objectives. Assessments of threats and damage typically require spatial resolutions of a few to a few tens of meters and revisit times of minutes to hours. These requirements are shifting towards more demanding levels, but they can be achieved by high-quality sensors on large constellations. Distributed systems would be well suited to performing damage assessment of strategic or conventional engagements because of their timely coverage, which is essential in planning follow up operations. Ideally, damage assessment would be available in tens of minutes, while delivery platforms were still in the area, although cycle times of hours can support follow up sorties. Current systems support a roughly daily cycle. The effectiveness of damage assessment would be greatly enhanced by the addition of active lasers or radars, which add depth resolution to remove the ambiguities involved in interpreting post-strike passive imagery today.

Detection of chemical and biological weapons is a related application that could take advantage of recent developments in active sensors. Lasers and detectors are now deployed in truck or aircraft mobile units for the detection of bulk aerosols. It appears possible to develop units using more precise fluorescence and DIAL measurements for the identification of specific chemical and biological agents that could be packaged in distributed satellites—in part because of their shorter ranges to targets. These sensors would represent both a global warning system for the introduction of such agents and a safe means of tracking their dissemination. As noted

earlier, there is significant benefit from deploying such sensors on distributed satellites, particularly for operation in a scanning mode.

Weather measurements are currently infrequent, incomplete, and poorly resolved. Passive scanning sensors could make a significant improvement in measurements of cloud cover. Active scanning sensors including lidars and radars would have a significant advantage in measuring detailed cloud compositions and distributions and wind patterns at all altitudes in an adequately timely fashion. The sensors for making such measurements should be sufficiently small, light, and efficient to be added on to commercial satellites.

Meteorological measurements also require revisit times of minutes to hours and spatial resolutions of tens to hundreds of meters. Active sensors required for improved measurements of cloud tops, bottoms, and structure for military planning and could also improve climate change and engineering measurements. Previously, cloud measurement requirements were limited to much coarser spatial resolutions. However, both military and scientific investigators now want spatial scales of about 10 m to address critical kinematic, exchange, and thermodynamic processes. These requirements—and those for surface ecological process—could become even more demanding over the next decade. Similarly, agriculture would like roughly 30 m resolution to check soil moisture, and few meter resolution for crop stresses. By this standard, Landsat has adequate spatial resolution for agriculture, but its utility is compromised by its 16 day revisit time and limited spectral resolution. Distributed systems appear ideal to address both needs.

Distributed communication links are possible with distributed systems. At a minimum, commercial communication systems will make several thousand voice-quality circuits available in the area of conflict. They could do much more. They could solve the current dilemma of the "last mile" distribution which results from the fact that high-bandwidth fibers can efficiently carry information to a central point in the theater, but not to the ultimate, distributed users of that information. Direct handset to satellite communication systems could provide needed two-way communication to both complete in-theater distribution and complement the one-way flow of direct broadcasting systems.

Distributed communications systems could do quite a bit more than that. For a constellation of a few hundred satellites, a few tens of satellites could be in sight at any given moment. Thus, they could transmit their signals with the appropriate delays to form a coherent communication array with high gain in any selected direction. That, together with their low altitude, would make it possible for the satellites to burn through jamming and provide clear communication to besieged or covert groups. A variant on this concept is the use of the constellation for the delivery of distributed, survivable precision global positioning in theaters. Alternatively, their coherent, directed, intense signal could be used for precision jamming of the opponent's communications. Another alternative is the use of high-gain coherent distributed networks for selective, sensitive electronic intelligence.

The high capacity available when current microwave cross links are replaced with laser cross links in about a decade should make possible the delivery of near-real-time, high-quality information from the whole theater and globe to war fighters. It should also make possible real-time, high-margin communication links from remote satellites and sensors to operators who can discriminate the targets in these signals. As sensor resolutions and communication bandwidths grow, this could emerge as the best way to remotely project man into the battlefield. The high

capacity cross links would be common to both distributed and central systems, but only the distributed systems could take full advantage of them in this manner.

An emerging, but unconventional, alternative is the use of massive, compact processors on board satellites, not just as bulk filters, but as thinking machines that can filter out noise by extensions of the moving target indication algorithms discussed above. With that capability they could identify targets, impose priorities, and prosecute the attack themselves. This is a little discussed possibility, but most of the key pieces were developed in the strategic defense program of the last decade. The main element now lacking is sensors that can look down and find targets in strong clutter, and as noted above, rapid progress is being made on such sensors.

Space surveillance is now performed from the ground with radars and telescopes. Distributed systems in space could maintain a more timely and complete survey of active satellites, debris, and the natural environment. Indeed, that mission could largely be accomplished as a part time function or by a small visible sensors added on to each of the platforms described above. The proposed adjunct mission of planetary defense has somewhat more demanding requirements, which cannot be fully satisfied by sensors on the ground. For them, space basing is natural and apparently cost effective. It could also be executed as an auxiliary mission of space surveillance distributed systems, although the sensors required would be a significant extension of their primary sensors. For these missions, there is a natural match between the SSTO and other initiatives to reduce cost to orbit, which is the essential feature in delivering on the cost performance estimated above.

Defensive and offensive operations from space are possible with response times of a matter of minutes. Distributed systems are appropriate hosts for brilliant kinetic munitions of either defensive or offensive orientation. The essential tradeoff is the number of interceptors against the velocity increment of each. These tradeoffs are relatively insensitive to application, and lead to modest numbers of affordable systems for most. Once deployed, these platforms would also be available for satellite self defense or space control, for which they appear ideally suited. An interesting alternative use is the correlation of the many occultations their transmissions would experience with ground receiver arrays to detect stealth satellites.

5.5.4 Related Applications

Related applications for distributed constellations include synergisms with other military, scientific, civil, and commercial space operations. As noted above, in the Gulf War, Landsat proved to be a useful source of interim synoptic multispectral data for coarse surveillance and targeting. Such cooperation could continue in the future. Not only Landsat, but also AVHRR, weather, and civil monitoring assets could be used to augment military assessments. Conversely, suitably desensitized information from distributed constellations could provide valuable information to civil agencies, which lack prompt information on land and water use, weather aloft, and pollution dispersion. There is a sound basis for a healthy scientific and programmatic exchange.

That basis is particularly clear in the areas of agriculture, environment, and the ecology, in which detailed information is now available on a global basis only on intervals of weeks (with reporting delays of months) of data with tens of meters resolution and only a few spectral bands. Any of the active or passive sensors discussed above would enhance by several orders of

magnitude the amount of information available to civilian scientists for the assessment of degradations of the environment or ecology and to commercial investigators for the assessment of domestic and global crop health and production.

A specific example is the Earth Observing System (EOS), which is a $10B set of experiments to sample the impact of man's activities on the environment. It could provide useful background, surface, and meteorological data to the military. In return, distributed systems could provide measurements of temperature, water, and winds aloft, which EOS has been unable to measure from its large, high altitude satellites. The same is true of burgeoning efforts at climate engineering, which needs even more timely data that only distributed systems could provide. Finally, there is the possibility of harnessing the simpler, affordable technology of Clementine-like defense missions to deep-space missions of other agencies and countries. In all cooperation with other fields, agencies, and countries appears to be a very fruitful and natural aspect of the development of distributed systems.

5.5.5 Distributed Sensors

Distributed sensors include both passive imagers and active sensors throughout the electromagnetic spectrum. This section discusses their relevance to the applications discussed in the previous section and their scaling advantages relative to small constellations. It also discusses the relative maturities of the various sensors that are now or soon will be available. Figure 2 overlays on the straight black lines of Fig. 1 the capabilities of various distributed radar, microwave, infrared, visible, and laser sensors to address the requirements discussed in the previous section. The capabilities shown are those of small sensors that could be deployed on light satellites for incremental payloads of roughly 100 kg, 1 cubic meter, and 100 Watt, although a number of the sensors—particularly the passive visible and infrared imagers—are now available for an order of magnitude less than that.

Missile (bus) warning is perhaps the most demanding in space and time resolution. Satellites and focal planes now exist to do this from low altitude. They would do so in a staring mode, which would reduce their leverage, but they would still have a significant advantage over performing the missions with larger satellites from longer range. However, as noted above, they would need to derive range information. If that could not be done from stereo viewing, which was not assumed in the above analysis, they would require active sensors for ranging. There would not be any advantage in deploying such active sensors by themselves in a distributed, staring mode. But they would have great benefit in improving the tracks from the passive sensors, so there would be a positive benefit in deploying both large focal planes and active rangers on distributed, low-altitude platforms. An additional benefit of distributed systems for missile defense is that they connect well with the distributed space based interceptor concepts that have been found appropriate for missile defense against a determined enemy because of their greater survivability and modular deployment and interaction. They could be a natural element of such defenses, should serious missile defenses again be found appropriate.

Global surveillance was perhaps the original stimulus for work of distributed systems and remains its most likely early beneficiary of it. That is because the requirement for global, prompt, medium resolution is precisely what current visible and infrared sensors are best suited to provide. Visible sensors provide the high resolution needed for target identification; they could also be used in registering the larger pixels from infrared sensors for data enhancement. It should be

possible to obtain roughly one meter resolution from small satellites. There are both commercial and military programs under way to do so. Infrared sensors can provide few meter resolution for night, hot, and moving target detection and damage assessment. They could also provide wide-area multispectral images of suspected deployments in vegetation.

Both the visible and infrared sensors could be deployed on small satellites as scanning sensors. If so, they would have a very significant advantage over larger, higher systems in providing similar resolution and coverage. If deployed in a staring mode (or equivalently with a requirement for coverage everywhere, all the time), their leverage would be reduced, but they would still appear to have more than a factor of two advantage over larger systems.

Damage assessment uses higher spatial resolution of limited areas that have just been attacked to evaluate whether the attack was successful. Small satellites can do that, too. There is no intrinsic limit to the resolution or registration that small satellites can provide. Current systems are working towards one meter from satellites that weigh a few hundred kilograms. The scaling of distributed systems for this application is as discussed above for global surveillance. In a scanning mode, they have high leverage; in a staring mode they have less but still significant leverage. There is, however, one additional point. The value of distributed systems for damage assessment would be greatly enhanced by the addition of ranging sensors, which could eliminate ambiguities in interpreting passive images. By themselves, active sensors would have modest leverage as scanners; none as staring sensors. But deployed in conjunction with visible and infrared sensors of either type, they would add significant value to the combination, and should be included.

Small SARs could also provide rapid revisits with meter resolution, which would be adequate for some military damage assessment and tactical intelligence. More importantly, it would provide such coverage in all cloud and weather conditions. As shown in Fig. 2, they could cover much of the very important medium resolution region. Like other active systems, SARs have modest leverage as scanners, not as starers. However, their normal sidelooking and spotlight modes of operation both scale and scanners, so they should have adequate leverage in either. Any when deployed in conjunction with any of the sensors described above, SARs should have great benefit because of their ability to do precision measurements in weather.

Detection of chemical and biological weapons is particularly suited to distributed systems. It is very difficult to detect chemical and biological weapons with passive remote sensing systems and it is dangerous and manpower intensive to search for them from the ground. Lasers and lidars are the sensors of choice, in that they can sense from long distances, identify specific chemical species precisely, and minimize exposure to personnel in the process. Lasers are essential for host of applications such as damage assessment, chemical and biological weapon detection and tracking, and cloud coverage measurements. They also have metric capabilities that are well suited to the measurement of structured, transient phenomenon in civil and commercial applications. Lidars have been developed extensively for back scatter and aerosol measurements; sensors for DIAL measurements are in development and on track for the allowable weights and powers for distributed deployment.

The scaling of lasers for this purpose is quite positive. The time lines for chemical attacks are such that revisit times of a half an hour or so are generally acceptable. Thus, the lasers can be deployed in a scanning mode, which means that they have significant leverage for being deployed

in distributed systems. If the time lines were such that they had to be deployed in a staring mode, they would have no leverage. However, if they were deployed as an adjunct sensor for missile warning or surveillance, they would add enough value to justify their inclusion as a staring system for chemical detection as well.

Weather is a very important but often overlooked aspect of military operations—until they actually have to be executed. Distributed systems could add to both the timeliness and resolution of weather information. The lower right of Fig. 2 shows the possible contributions from real aperture radar arrays for 10-100 m resolution of weather and threat clouds with » hour revisit times. Such resolutions would also be adequate for the detection of some military targets, the assessment of cloud cover, disaster control, and the assessment of vegetation. Such radars have recently been reduced in size and power to appropriate levels for distributed applications, in which their radiating arrays and mechanical issues would be greatly reduced.

Radars do not obviously scale well for distribution. They are active and hence scale as r^2. They are also capable area search sensors, in which their number scales as $1/r^2$ for applications such as aircraft or cruise missile search. Thus, their total cost is independent of r, and there is no benefit for distribution. For that reason, previous studies have looked at very large systems, hoping for economies of scale, which have not emerged. Alternatively, it could be recognized that with a satellite coming over every half hour it is possible to have each one observe the aircraft and to make an estimate of its plan. If so, the number of satellites scales as 1/r, the total cost is proportional to r, and there is a strong benefit for distribution. That would just require a different way of looking at the problem.

Microwave sounders have also been developed extensively. Deployed on distributed constellations, they would be much more effective, and could provide detailed cloud and water profiles rather than just integral measurements. While active, they naturally operate in a down-looking mode, which is effectively scanning, so their leverage is generally high enough to justify inclusion, even if they weren't very small. But the real reason for deploying them on small satellites is that from very low altitudes they can do much finer vertical resolution of clouds, and from very many satellites they can essentially to tomography of the clouds.

Distributed communication links are possible with distributed systems, although as noted above, they do not necessarily scale well. The earliest impact of distributed communications in theaters is likely to be the addition of a large number of voice quality circuits. The second could be the solution of the "last mile" problem, which both fiber lines and long-haul satellite systems have. If it was possible to inject the signals from these long-haul systems into distributed satellites, they could redistribute it rather efficiency—using idle bandwidth. As noted above, distributed communication systems scale as r^2. As area communication nodes their number must scale as $1/r^2$. Thus, their total cost is independent of r, and there is no benefit for distribution. However, if the communication systems have already been built for service of non-hostile theaters, they are essentially free for the price of a mobile gateway to inject the signals into them. For that reason, distributed communications in theater appears very advantageous.

Space surveillance does not appear on Figs. 1 and 2, but it does underpin each of the applications, in that space surveillance keeps track of the myriad threats to the satellites that provide the services indicated. Moreover, distributed space systems could maintain a more timely and complete survey of active satellites, debris, and the natural environment. The low Earth

orbit threat could be largely tracked as a part time function or with small visible add on sensors. It is difficult to perform a useful cost-benefit estimate, but given the cost and manpower requirements of the current radar and GEODSS systems, it seems quite plausible that could be a viable option. For the objects in synchronous orbit, larger sensors would be needed. They would require some additional development and deployment, but given the increasing value of objects there, the effort seems justified. Such sensors would also support the proposed mission of planetary defense, which has still more demanding requirements.

Defensive and offensive operations from space are attractive because of the possibility of response times of minutes. That distributed kinetic energy is the preferred mode for strategic missile defense was established in the last decade. There are now strong arguments that it may be preferred for theater missile defense as well. The notion of offensive operations from space are newer. While they are unfamiliar, and hence opposed by some, they do have certain advantages. The first is timeliness. A few kilograms delivered at 7 km/s in a few minutes is probably worth a few megatons delivered a few days later. The second is accuracy. It now appears that projectiles from space can take advantage of the same suite of sensors as other precision munitions to strike within meters. The third is cost. It appears possible to deliver such a round from space for a cost on the order of a million dollars. If so, that is competitive with other means of interdiction. for reaction times from minutes on the order of tens of minutes, distributed deployment is both appropriate and effective to other basing modes.

5.5.6 Technology Status

The status of sensor technology is roughly represented by the visible and infrared cameras developed by Lawrence Livermore National Laboratory for missile defense applications and for Clementine's mapping of the Moon. Those earlier applications used roughly 400 x 400 detector silicon visible and 128 x 128 detector platinum silicide infrared array focal plane arrays with few to few tens of centimeter optics. A few years later, the current systems can use megapixel silicon and indium antimonide arrays for roughly the same costs. These sensors typically weigh on the order of a kilogram, consume a few watts of power—including their coolers, and produce images with few to few tens of meter resolution, which is more than adequate for applications discussed above.

Lidars are evolving rapidly. Their power has increased and their size has decreased from the roughly 1 ton, 8 kilowatt versions built for the Gulf War to roughly 100 kg, 3 kilowatt versions for environmental assessments and 200 kg, 1 kilowatt versions for space applications. They have provided quantitative measurements of important meteorological variables, including spatially resolved Raman measurements of water vapor distribution over typical terrain and temporally and vertically resolved measurements of water vapor over tropical mixing layers. Lasers are rugged and reliable; advanced diode lasers could be developed to much higher efficiencies. Thus, they could soon be practical tools on most small satellites. There are similar developments in radars and SARs that could support the applications shown, although there are restrictions on their development.

Landsat was a useful interim solution in the Gulf War; it has a number of more capable successors. The Miniature Sensor Technology Integration (MSTI) series of satellites has the goal of developing small sensors more useful for defense. MSTI-1 flew in 1992, accumulating 100,000 MWIR background images during its longer than expected lifetime. MSTI-2 was

designed to detect and track missile launches in multiple IR bands relevant to water vapor. MSTI-3 and its successors will test advanced visible and IR sensors and tracking, culminating in the flight of a lidar with an auxiliary mission of environmental and ecological disaster monitoring. A number of small satellites such as ALEXIS have demonstrated unexpected robustness in their response to deployment problems during launch that could have negated more sophisticated satellites. Their modest control requirements, short and economical fabrication schedule, and demonstrated reliability show that while light satellites can be cheaper, their performance need not be inferior to that of larger ones.

5.5.7 Platforms for Distributed Sensors

Platforms available for distributed deployment include dedicated small satellites, commercial satellites, and new communication constellations. Dedicated satellites have obvious advantages in schedule and deployment flexibility, but would cost the most, although costs might be reduced on the basis of recent missile warning and defense technology. Distributed sensors are sufficiently small to be added to most or all new or replacement satellites of commercial constellations. However, few constellations offer enough platforms to provide the close spacing distributed systems need.

An alternative deployment is on the new handset-to-satellite communication constellations, with which distributed systems have obvious synergisms. Both require continuous global coverage with modest links—and hence low altitude deployments. These communication constellations have a great deal of capacity in the form the sensors need. At any time, much of it is unused—particularly in the less-developed areas that are the focus of much of the current concern of theater operations. Small sensors could tap the power available there to gather the information and use the large unused bandwidths in underdeveloped areas to transmit it back. The combination of light add-on sensors on such satellites could provide good, timely global surveillance for little cost. Such arrangements could lead to more fruitful discussions of potential interactions of defense and non defense distributed constellations. The two could learn how to cohabit space, jointly address issues such as debris, and find accord on space surveillance. They could lead to arrangements for renting, internetting, and sharing bandwidth in peace and conflict. However, there could be resistance to such measures from both domestic sources and from consortia with foreign partners and users, which could inhibit cooperation.

5.5.8 Timelines for Distributed Systems

Timelines for evolution of distributed constellations are unclear. There is a somewhat negative impression of small satellites due to DARPA's programs, which convinced some that small satellites were intrinsically expensive and only capable of carrying inferior sensors. There was a positive, transient impact due to the Gulf War's exposure of the U.S.'s lack of a wide-area surveillance system, but that has subsided again the traditional bias towards very large, capable, and expensive systems of the type the services have traditionally preferred. Together with the continuing downward pressure on DoD and space budgets, that has led to the current situation in which there is again minimal current or planned development of distributed systems.

By contrast, the planning timelines for non-defense distributed constellations are rather aggressive. There are currently about 6 commercial consortia for distributed communication constellations which have plans to deploy significant numbers of satellites within the decade.

There are also about 4 commercial ventures to develop constellations for distributed imaging within the decade. All are using the current level of technology for their satellites, sensors, computers, and communications. The overall result is that these commercial systems are now moving faster, with better technology, than DoD systems, which could make it more difficult to achieve a working relationship with them later.

5.5.9 Summary

There are a number of applications for which small sensors on many satellites scale well. This paper has addressed that scaling analytically and applied it to find the applications for which distributed systems scale best. Some, like passive scanning imagers on dedicated satellites or communication constellations, scale very well indeed—offering a way to fill the current gap in wide-area surveillance quickly for little expenditure of funds or effort. Active sensors and communication systems scale more sensitively and depend on the coverage required. Each application has to be examined carefully to see how its costs scale in such a constellation, but there are enough applications for which the results are positive to make the area interesting for development.

Applications for distributed systems range from missile warning through global surveillance to communications, space surveillance, and control. The scaling for each has been examined and shown to be favorable through a process that derives certain principles that can be used to evaluate other proposed applications. For example, missile warning not only justifies the deployment of distributed passive imaging systems, it also justifies the deployment of active lasers that are useful for other applications such as global surveillance, damage assessment, and the detection of chemical and biological agents. Damage assessment justifies the deployment of small SARs, which are also valuable for all-weather surveillance. Weather an aircraft justify the deployment of radars and sounders which would be vulnerable and less effective on larger platforms. Kinetic energy provides both a defensive and offensive capability to the constellation. The ability to connect to long-haul communication assets enhances their potential as an in-theater distribution system.

There is a well developed store of sensors for distributed applications including passive imaging sensors and active sensors throughout the electromagnetic spectrum, whose weight, volume, power, and cost meet the requirements for effective deployment. Modest constellations can meet both the spatial resolution and revisit times required. Radars can provide wide-area coverage of weather, threat clouds, an air traffic. SAR, infrared, and visible sensors can provide high resolution assessments. And lasers can provide accurate ranging and chemical and biological threat assessment. There is an extensive data base on the development of adequate sensors for each of these applications.

While dedicated platforms would be preferred, the possibility of add on deployment on new communications offers many synergisms and opportunities for cost savings. There is a basis for DoD/civil/commercial cooperation, although civil research is in decline because of budgetary pressures, and foreign participation and bandwidth competition could inhibit cooperation with commercial ventures. The likely result is little DoD development and aggressive commercial development of distributed systems for a number of applications. If so, the DoD could be displaced from distributed constellations, denied the early global surveillance it could

produce, and forced to purchase or rent such communications and surveillance services from international suppliers within the decade.

5.5.10 Enabling Technologies

Enabling technologies for distributed systems are indicated in the text above and in the appendix, but they are collected here for clarity. There are a large number of enabling technologies, this section discusses only the most important. The primary one is, of course, recent developments in the ability to cheaply and efficiently build, launch, and control small spacecraft and the sensors that go on them. A key element of this is the application of industrial methods to the production of spacecraft, such as Lockheed's fabrication of the IRIDIUM buses for Motorola, which is taking place at about 10% the cost and 1% the time of defense systems. No less important is industrial progress in minimizing the manpower required to run quite competent satellites. Further developments in each would be extremely valuable in further improving an already favorable tradeoff relative to small constellations of large satellites. In this area, further reduction of launch costs, particularly of multiple satellites, would be most helpful.

Particularly rapid progress has been made in a few key technologies. Some, like computers and materials, are well known. Without the 2-fold advance in computers every 18 months, it would not be possible to consider the level of on-board computation required to support such sophisticated sensor suites. The rapid turnover of technology, is an integral part of an alternative hierarchy of distributed systems. That also holds for the sensors themselves. Megapixel visible and infrared arrays, lasers, lidars, DIAL, radars, SARs, microwave sounders, light apertures, and space based kinetic energy have all made rapid progress. Just how much can be carried on a distributed system depends on how much progress they make in the next decade. Their quantitative development will determine just how much can be put on given satellites, and their qualitative development will determine which new missions can be addressed.

There are also some externalities that have great potential leverage. The large number of commercial communication satellite systems such as IRIDIUM planned for the next few years offer significant avenues for multiplying defense capability and bandwidth through cooperation. Another important externality that emerges as a by product of distributed systems is the greater survivability, both of the small individual platforms and of the distributed system. With adequate attention to the supporting technologies, this could become a dominant feature of distributed systems. The final point is the simple scaling of the sensors, platforms, and missions of concern in the coming decades. They simply fit together well. Distributed systems do not dominate all applications, but for those for which they do scale favorably, the mission and technology themselves give them a great deal of leverage.

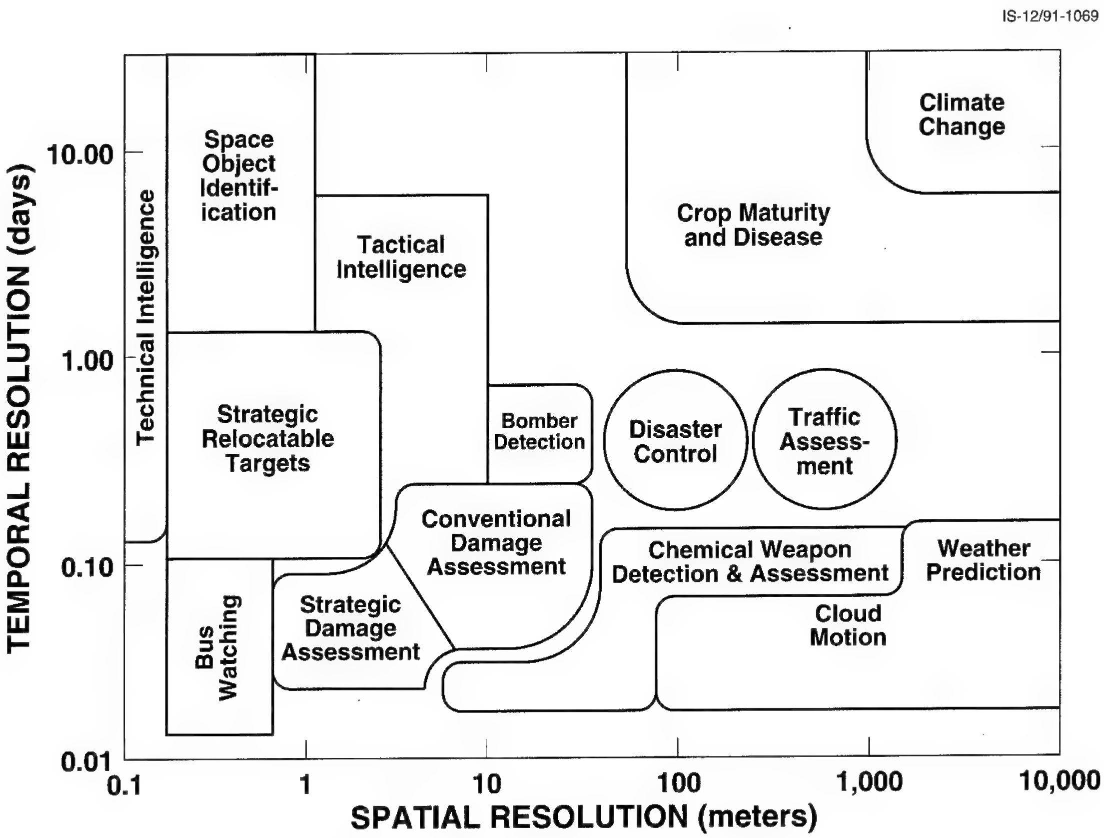

Figure 5.5.1 Temporal and spatial resolution required for various defense and civil remote sensing applications

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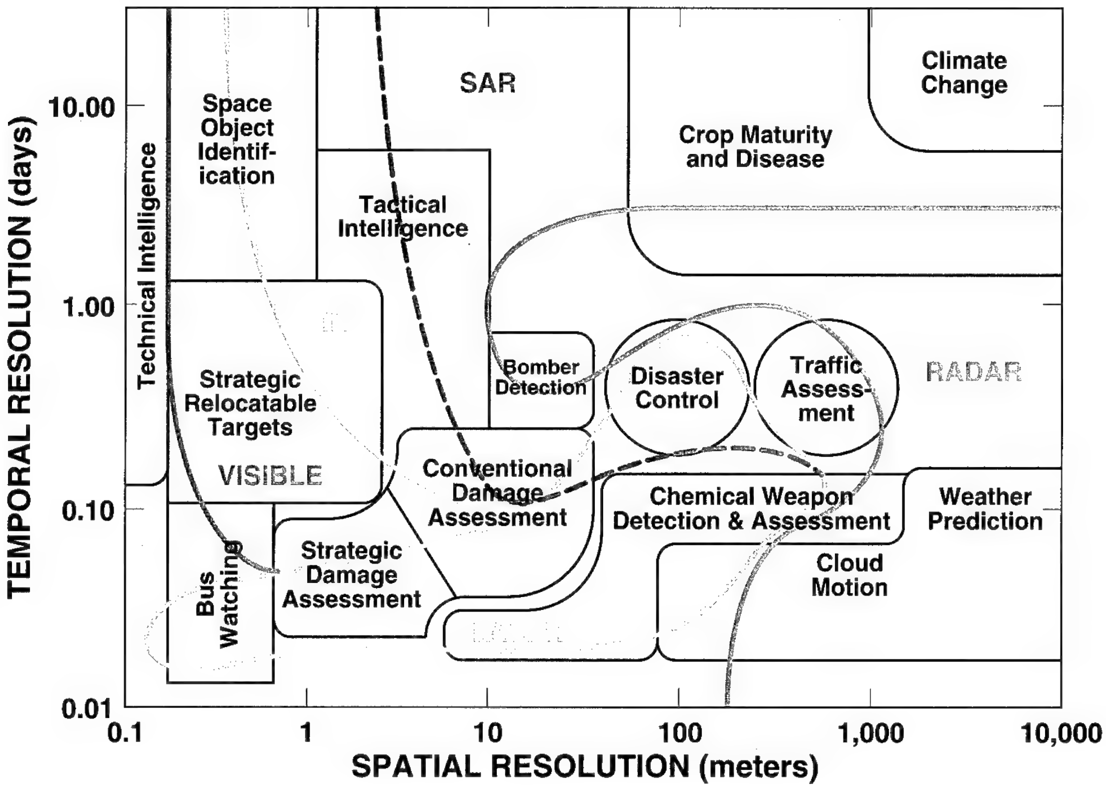


Figure 5.5.2 Distributed sensor capabilities for defense and civil remote sensing applications

Appendix to Section 5.5: Scaling of Distributed Systems

Distributed systems have many satellites, each with modest sensors and communication capability, whose integration gives the whole constellation global, real-time coverage. For some missions, such constellations have significant advantages in scaling, performance, and survivability. This appendix discusses the missions for which those benefits can be realized. The advantages of distributed systems result from their reduced ranges to their targets and between the satellites in their constellations.

Passive distributed sensors demonstrate the benefits that result from reducing the range to target. A sensor of diameter D operating at wavelength λ has resolution $d_{min} \approx r\lambda / D$ at range r; thus, achieving resolution d_{min} at r requires a diameter that increases with range as $D \approx r\lambda / d_{min}$. The sensor's aperture area increases as r^2, and its volume and cost increase as roughly D^3, for a given level of technology. A constellation of N satellites has a revisit time $T \propto \lambda / Nr$, so that for a given revisit time, $N \propto \lambda / r$. Multiplying the cost per sensor times the number of satellites gives a total cost $C \propto ND^3 \propto r^2$, which indicates a significant reduction in cost for operating more satellites at shorter ranges, e.g., there is an advantage of about a factor of 4 for deploying twice the number of satellites at half the range.[1]

These results can be extended to incorporate constellation altitude, which provides additional insights. From a satellite at altitude h, the range to a target at cross range y is $r = \sqrt{(h^2 + y^2)}$. If the satellite is responsible for a transverse ground swath 2W, the maximum range to its targets is $r_{max} = \sqrt{(h^2 + W^2)}$, for which a sensor operating at wavelength l must have diameter $D \approx r_{max} \lambda / d_{min}$ for resolution d_{min}. The aperture required increases with range as $(r_{max} \lambda / d_{min})^2$; its volume and cost roughly as $(r_{max} \lambda / d_{min})^3$. For a constellation of N satellites, the revisit time is $T \approx 4\pi R_e^2 / 2zVWN$, where R_e is the Earth's radius, V is the satellite's speed, and z is a constant (≈ 3) that depends on the extent and uniformity of coverage in latitude.[2] Inverting this relationship gives the number of satellites required to support a given revisit time

$$\mathbf{N \approx 4\pi R_e^2 / 2zVWT \propto 1/WT.} \qquad (1)$$

A few tens of satellites with few hundred kilometer swaths give few hour revisit times. The constellation cost is proportional to the product of the cost per sensor (and satellite) and the number of satellites, which is

$$\mathbf{C \propto (4\pi R_e^2 / 2zVWT)(r_{max} \lambda / d_{min})^3 \propto (h^2 + W^2)^{3/2} / WTd_{min}^3.} \qquad (2)$$

C increases as 1/T as the revisit time is decreased; it increases very rapidly as better resolution is required. For W small, C is large because N is large; for W large, C is large because the range and hence the sensors are large. C has a minimum at an intermediate value that can be found by introducing the variable w = W/h, the swath half width in units of constellation altitude, in terms of which Eq. (2) is

$$\mathbf{C \propto h^2 (1 + w^2)^{n/2} / w} \qquad (3)$$

The total cost is minimized by reducing h to the lowest value consistent with practical operation of the constellation. The exponent n, which is 3 for the passive sensors discussed above, is generalized here to show the sensitivity of costs to the scaling of the sensor size and cost on range. Figure 1 shows the scaling of N and C on w for n = 3. N falls as 1/w from 4 at w = 0.25 to $\approx$ 0.5 at w = 2.3. C falls from $\approx$ 4.4 at w = 0.25 to $\approx$ 2.6 at w = 0.75, but rises again to

≈ 7 by $w = 2.3$. Thus, there is a factor of two penalty in cost for operating scanning passive sensors a factor of two away from the optimum swath. The minimum C can be confirmed by differentiating Eq. (3) to produce $w_{opt} = 1/\sqrt{(n - 1)}$, which for $n = 3$ is $= 1/\sqrt{2}$, as shown.

For smaller n, w_{opt} moves to larger values, as shown in Fig. 2, which compares the costs for $n = 2$ and 3. By $n = 2$, which would be appropriate for optics that scaled as the aperture area rather than volume, the minimum in the curve moves to $w_{opt} = 1$ and its value drops from ≈ 2.6 to 2. With decreasing n, the cost curve becomes much flatter, so there is less of a penalty for operation at separations larger than optimum. However, the significant penalty for operating at swaths much smaller is altered little for smaller n.

C varies as $\sqrt{[n^n/(n-1)^{n-1}]}$, which is shown in Fig. 3. As n falls from 3 to 1.5, the optimum range increases from about 0.7 to 1.5 and the optimum cost drops from 2.6 to about 1.6. This analysis does not show that it is better in general to operate at longer or shorter ranges, only that for each sensor there is an optimal range that is set by its scaling characteristics and that the penalties for operating far from that optimal range could be a factor of two or greater. Independent of the optimization of swath width, it is advantageous to operate distributed systems as low as possible. Having done that, the swath can be optimized through a process that more restrictive for large n, less so for small. Then, increasing T would decrease cost at the price of less timely data, and degrading resolution would decrease cost, but at the price of an equivalent or disproportionate degradation of the value of the data. Increasing T or d_{min} would appear to be the final steps in attempting to reduce costs to affordable levels. If that is not possible without unacceptable degradation of performance, it may be necessary to shift to the staring sensors discussed below, which have added degrees of flexibility.

The scaling arguments above are based on range and aperture size. The number and cost of the detectors in the focal plane and the computational power to support them should also be taken into account; however, that does not change the above results. When computer and detector costs are included, the constellation cost of Eq. (2) is generalized to

$$\mathbf{C \approx N[a(W/d_{min})(V/d_{min}) + bW/d_{min} + cD^3]}, \tag{4}$$

where a, b, and c are constants. On the right hand side, the second term is the number of detectors in the linear focal plane, W/d_{min}, times the cost per detector, b. The first term, which is proportional to the product of the number of pixels and the rate at which they are crossed, V/d_{min}, gives the computation rate required to support the focal plane. The third term gives the cost of the aperture, which is discussed above. Since the first and second terms are both proportional to W, they can be combined into $[aV/d_{min}^2 + b/d_{min}]W$. The two terms in brackets scale differently on d_{min}, which is important for studies of resolution, but for fixed d_{min} and cost parameters, their sum is a constant. Since it scales as W, and N scales as 1/W, the product of the sum and N is independent of W. Thus, its derivative with respect to W vanishes and does not affect the optimizations studied above. For passive scanning sensors, detector and computer costs add a fixed amount to the total cost, but do not affect the optimization with respect to W, which remains as shown in Figs. 1 to 3.

It is possible to estimate the rough increase in costs due to computers and focal planes. Factoring out the coefficient of the third term in Eq. (4) gives

$$\mathbf{C \,\alpha\, ch^2(\lambda/d_{min})^3[(aVd_{min} + bd_{min}^2)/ch^2\lambda^3 + (1 + w^2)^{3/2}/w]}. \tag{5}$$

The values of the cost parameters are not known precisely, but can be estimated well enough to give some guidance. A system with a 1,000 detector linear array might cost ≈ \$1K, including detectors, electronics, and integration; if so, b ≈ \$1/det. A 100 million instruction per second computer can now be flown for about \$100K, so the computational cost parameter is a ≈ \$0.001s. While the Hubble telescope cost ≈ \$100M for a few m^2 aperture, strategic defense systems proposed orbiting lightweight ≈ 10 m optics for \$100M. A geometrically intermediate cost target for aperture is c ≈ $\$10M/m^3$, which is given per unit volume rather than area to account for finite thickness and the greater support required for larger apertures. For these values of the cost parameters, resolution d_{min} = 10 m, a visible-near IR sensor, and h = 1,000 km, the first term in Eq.(5) is ≈ $[\$0.001s \times 10^4 m/s \times 10m + \$1/det \times (10m)^2] / [\$10M/m^3 \times (10^6 m)^2 \times (10^{-6}m)^3] \approx (100 + 100\$\text{-}m^2)/\$10\ m^2 \approx 20$. Thus, for these parameters, fixed costs are significantly larger than variable costs, so any variation in fixed costs due to factors not treated here could significantly impact the optimizations above. For operation at lower altitude, this sensitivity would be further enhanced. However, fixed costs scale less strongly on resolution than the costs for aperture. If 3 m resolution was required, the cost for the focal plane would drop to about that for aperture. For 1 m resolution, the cost for computation would drop to about that for aperture, too, although scanning sensors for continuous, whole-Earth coverage might require excessive array sizes and bandwidths.

Active sensors such as lidars, radars, and SARs scale slightly differently. In general the product of their power, P, and aperture, A, scales as r^4, which suggests a stronger scaling than that of passive sensors. However, for active sensors P and A can be optimized separately to minimize cost. Sensor costs are typically the sum of the costs for P and A, which is minimized by the choice $A \propto P$, which gives $PA \propto P^2$ a (cost per sensor)^2, so the cost per sensor only increases as $\sqrt{(PA)} \propto r^2$. Thus, the actual scaling exponent for distributed active sensors is n ≈ 2, for which cost as a function of w is shown by the bottom curve in Fig. 2. It is very broad, with a minimum at a half swath of 1 constellation altitude. While it is not appropriate to compare the costs of passive and active systems, which involve different missions and component costs, it is proper to note that active systems would operate at about 30% greater range than passive systems on average. They could do so because optimizing both P and A allows them to increase range with less penalty in sensor cost.

Communication satellites have distinctly different scaling in distributed operation. While they would not normally be used in a scaling mode (apart from store and forward systems), their scaling in that mode can be discussed simply. The key issue is the link margin between the satellites and ground stations. If the satellite has a dish of diameter D and aperture area A, the power density it delivers at range r is $\approx P/(r\lambda/D)^2 \approx PA/(r\lambda)^2$. The signal received by an aperture A at that range is proportional to PA^2/r^2. Since P and A can be optimized separately, the channel cost is proportional to P, while PA^2 scales as P^3, so the cost per channel scales as $r^{2/3}$ and the scaling exponent is n ≈ 2/3, for which the above optimization does not apply. The practical answer is to move long-haul communications satellites as far apart as is convenient, which is where Earth curvature effects modify these arguments. Long-haul communications satellites do not distribute favorably, and should be deployed much as they are at present.

An exception to this result is the active and growing area of distributed communication from satellites directly to user handsets and pagers. For such scanning systems, the key link is from the handset to the satellite, which is limited by the power that is allowed and the antenna

gain that will be tolerated. The former is set at $p \approx 3$ Watt by the FCC; the latter is dictated by customers, who do not care to point high-gain antennas at satellites. Thus, rather than the $(D/l)^2$ gain of long-haul systems, personal handsets have essentially no gain, so the received signal reduces to $\approx pA/r^2$, whose optimization involves only A. Then, the cost per satellite scales as r^2, $n = 2$, and the scaling of direct communication satellite systems is much like that of active systems. From Fig. 2 their optimum swath is at ≈ 1, although the penalty for operating with wider swaths is modest. Staring sensors. An interesting variant on the scaling discussed above is given by missile launch detection and other applications that require the sensors to observe most of the surface of the Earth at all times, which changes the basis of constellation sizing from scanning in a given revisit time to complete coverage at all times. If each satellite is responsible for staring continuously at an area pW^2 below it, the number of satellites required is roughly

$$\mathbf{N \approx (4\pi R_e^2/\pi W^2).} \qquad (6)$$

If the cost per sensor scales as $D^3 \alpha (r_{max}\lambda/d_{min})^3$, the constellation cost is

$$\mathbf{C \alpha (h^2 + W^2)^{3/2}/W^2 \alpha h(1 + w^2)^{3/2}/w^2,} \qquad (7)$$

which again shows the importance of operation at low altitude—although the advantage is linear, and hence somewhat reduced from that for scanning sensors. Figure 4 shows N and C as functions of w. N drops sharply as $1/w^2$. C increases sharply at small w due to this variation of N. C drops to a fairly sharp minimum at $w \approx 1.4$, and then increases sharply, approaching the asymptotic C α w by $w \approx 2$. If the exponent in Eq. (7) is generalized to n/2, the optimum w can be found by differentiation to be $\sqrt{[2/(n-2)]}$, which is $\sqrt{2}$ for $n = 3$, as shown. This result also shows, however, that for n less than or equal to 2, the cost does not have a minimum, and there is no benefit for distributing staring sensors within this analytic model.

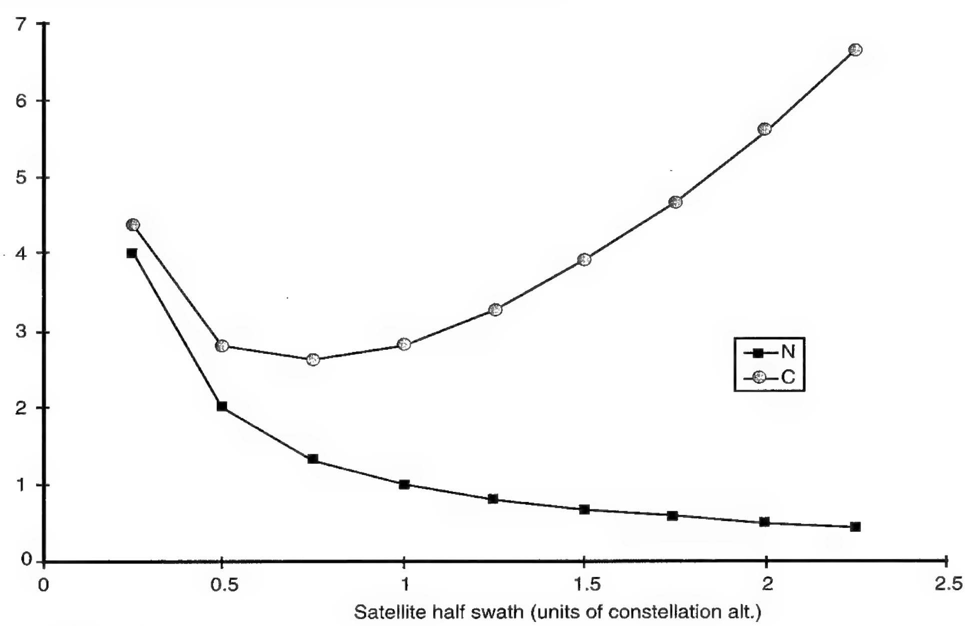


Figure 5.5 App -1

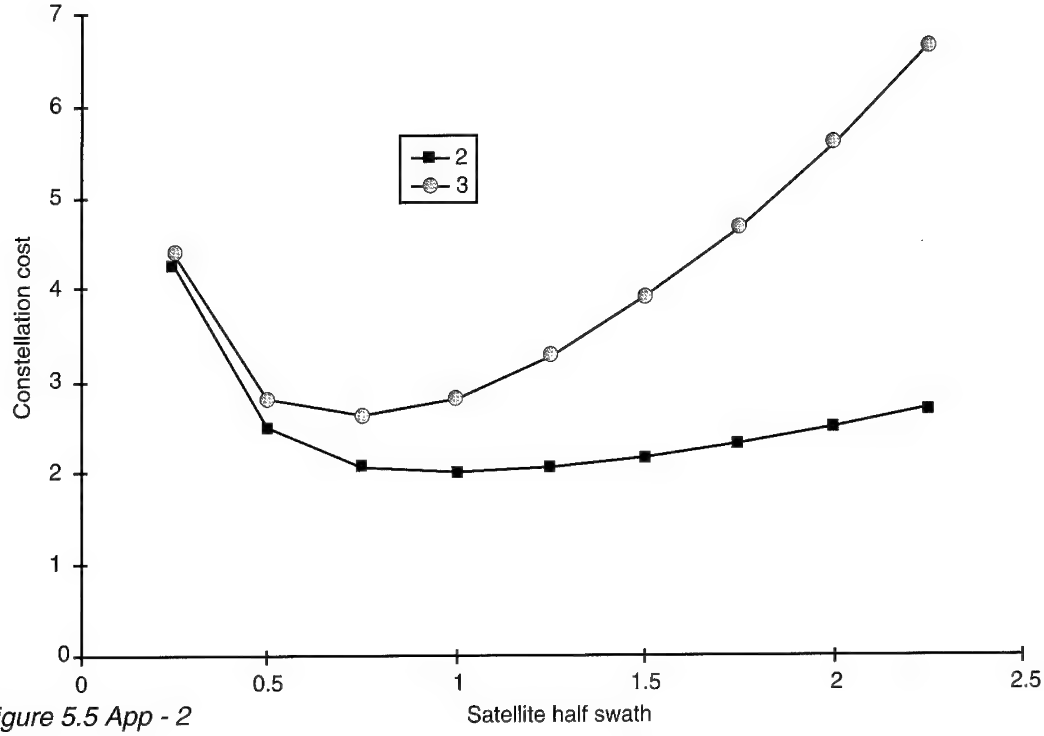


Figure 5.5 App - 2

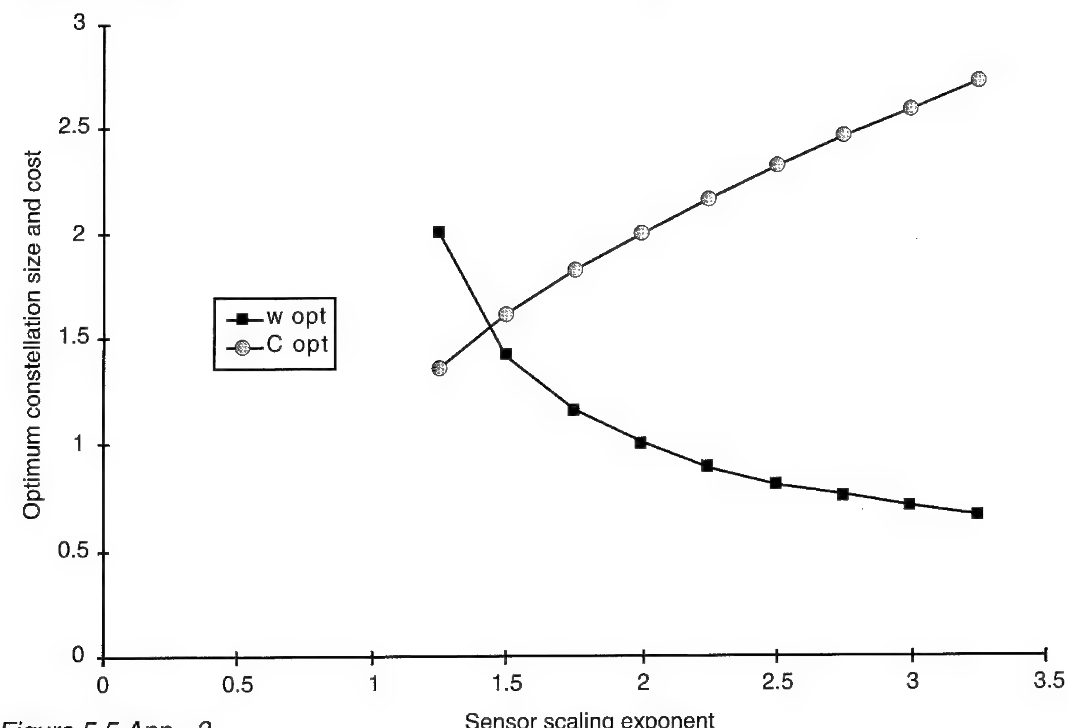


Figure 5.5 App - 3

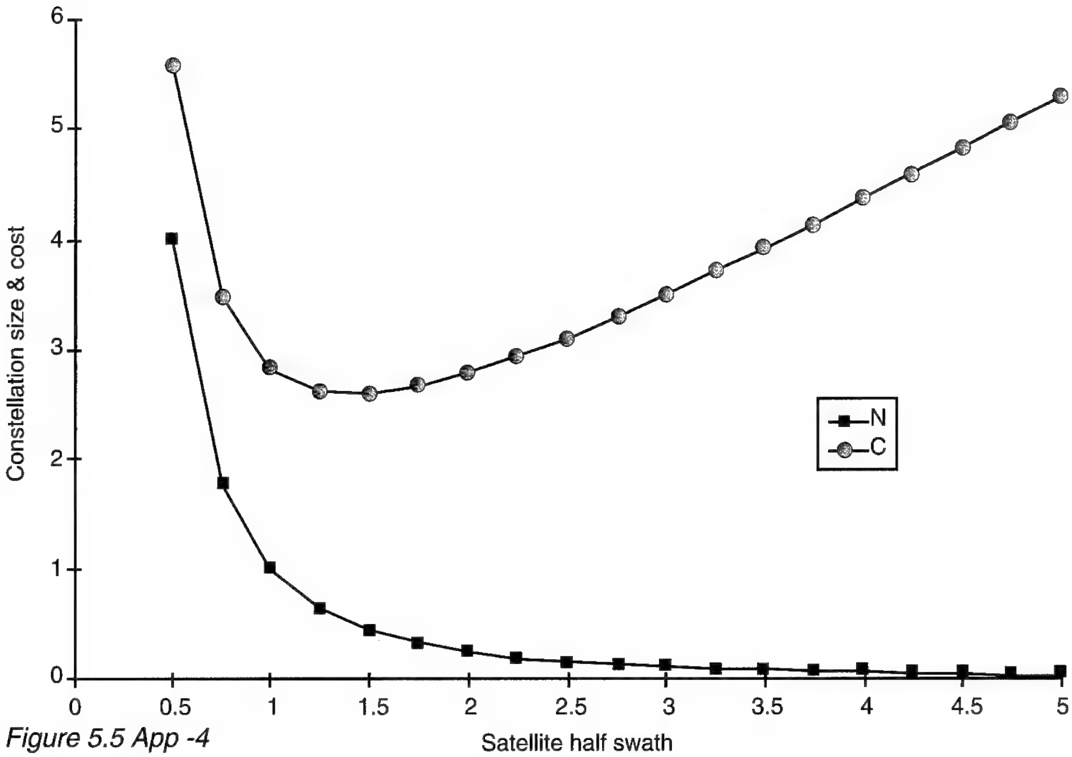


Figure 5.5 App -4

1. G. Canavan and E. Teller, "Low-Level Satellites Expand Distributed Remote Sensing, " *Signal* August 1991, pp. 99-103.
2. G. Canavan, "On Satellite Constellation Selection," Los Alamos National Laboratory report LA-12059-MS, May 1991.

5.6 The Human Role in Air Force Space Applications

Harry Wolbers

5.6.1 Introduction

Too often in system design an artificial dichotomy is created that attempts to classify systems as manned or unmanned. This especially seems to be true when referring to space applications. In reality there is no such thing as an unmanned system. Everything that is created by the system designer involves the human element in one context or another. The point at issue is to establish in every system, whether the system is controlled directly or remotely by humans, the optimal role of each human and each machine component.

It is the thesis of this paper that maintaining Global Presence, Global Power and Global Reach beyond the 2020 time period may well require the direct participation of Air Force personnel operating in space rather than relying entirely on remotely controlled systems as is now the case. The unique Air Force interests in supporting our space assets can not be abdicated to other agencies, countries, or commercial ventures. Rather, the Air Force infrastructure must be prepared, when appropriate, to directly utilize manned space capabilities to support the DoD overall space missions.

5.6.2 Historical Precedents and Past Experience

In the mid 1960's the Air Force initiated the development of a Manned Orbital Laboratory (MOL) which was to have operated in a low Earth orbit for classified missions. The program was canceled before the MOL became operational for various reasons, including budgetary, political, and the rapid parallel development of specific unmanned systems. In the years since the MOL was canceled considerable experience has been obtained in manned space systems including the Apollo Lunar Landing missions, the very successful Skylab (the Nation's first Space Station), and the Space Shuttle missions which have included the Spacelab missions and various special purpose missions such as the repair of the Hubble Space Telescope. In view of the developments of the last three decades it would seem appropriate to re-examine once again the human role in Air Force space applications.

Since the first manned spaceflight of Yuri Gagarin in Vostok 1 in 1961 (4/12/61) through the end of 1993, the former USSR had logged a cumulative crew total of 9,782 man days, 34 hours and 32 minutes in space. The U.S. had logged a cumulative crew total of 3320 man days, 6 hours and 44 minutes. Together these figures represent nearly 13,104 man days or 36 man years in space.

During this period 308 individuals, males and females, representing 25 different countries participated in one or more space missions. In these missions nearly every conceivable human task has been demonstrated as being feasible to be conducted in space provided that the necessary supporting equipment is available. Electrical and fluid systems have been repaired, large objects have been moved or replaced, and instruments have been re-calibrated and realigned. In the early 1974 Skylab missions the large food lockers (in excess of 6 cu, ft and weighing over 250 lbs) were very readily relocated in zero gravity by one crewman working alone. (A task that required four men on the ground). More recently the repair mission to the Hubble Space Telescope

demonstrated the utility of human intervention to repair and upgrade free flying satellites, thereby extending indefinitely their operational lifetimes.

5.6.3 Current Trends

At least 27 different countries currently have payloads in Earth orbit. In addition to the launch vehicles utilized by the U.S. and the former Soviet Union, other players are rapidly coming on the scene. The French Ariane has had a number of successful launches and the Japanese are rapidly improving their launch vehicle capabilities. As reported in the open literature (Aviation Week and Space Technology 3/20/95) Japan is working to double the lift capacity of the new H-2 launch vehicle. The Japanese are increasing their planetary programs and have stated their intent to become a leader in Earth Observations. Some $69 million dollars (U.S. equivalent) are currently budgeted for development leading to the H-2 Orbiting Space Plane (HOPE). In addition Japan spent $496.8 million (U.S. equivalent) in 1994 and have allocated $746.8 million (U.S. equivalent) in their 1995 budget to develop the Japanese Experiment Module (JEM) which is a manned research and development facility currently planned as an element of the International Space Station (Space Station Alpha).

Other players with orbital launch capabilities include India and the Peoples Republic of China. As reported in the press (Aviation Week and Space Technology - 2/27/95) the PRC's current Five Year Plan (1995-2000) includes a Satellite to orbit the Moon in the year 2000.

Before the year 2020, Space will no longer be the sole province of the United States or Russia. The capabilities to support humans in orbit will continue to increase and through competition and technological improvements launch costs will decline. The advent of many new players will undoubtedly require that current U.S. Policy and International Treaties be revised. Given the emerging technological capabilities and the demonstrated capabilities of human involvement in the deployment, servicing, and operation of space systems, it is our belief that the Air Force would be remiss if it does not actively exploit the human resource where appropriate when developing future systems.

5.6.4 Human Capabilities

A detailed list of human capabilities applicable to space mission activities may be found in many references.[1] A listing of typical human capabilities (categorized by Sensory/Perceptual, Intellectual, and Psychomotor/Motor abilities) is presented in Table 1.

While considerable quantitative data may be found in the literature defining human sensory discrimination abilities and the fine and gross motor responses that humans are capable of making, the higher level intellectual functions such as cognition are not as precisely defined in terms that can be used directly by program managers and system engineers in the design of new systems and applications. Fortunately pertinent research programs to overcome this deficiency are now underway at the USAF Armstrong Laboratory. These programs are making significant progress in defining and describing the underlying factors key to the effective use of human intellectual capabilities in the design and operation of future Air Force systems, regardless of the physical location of the human operator of those systems.

1. McDonnell Douglas Astronautics Company, The Human Role in Space, 5 Volumes, NAS8-36511, December 1985

For those "Intellectual" capabilities listed in Table 1 the following definitions may be helpful:

Cognition is defined as awareness, immediate discovery or rediscovery, or recognition of information in various forms. It involves comprehension or understanding. Information acted upon by the human element can be in the form of figures, symbols, semantic units, behavioral units, classes, relations, systems and transformations.

The terms cognition and perception overlap to some degree. Both perception and cognition are concerned with input information from sensory sources. Perception, however, is concerned primarily with sensory properties and with the cognition of figural units. The complete cognitive process includes operation with symbolic, semantic, and behavioral concepts as well. Perception is midway along a continuum extending from sensing at one end to thinking at the other end. It is the process of organizing and interpreting sensory inputs based upon past experience. Cognition involves a broader range of mental activity including awareness of semantic meaning and abstract concepts.

Memory is defined as information retention and storage, with some degree of availability of information in the same form in which it was committed to storage and in connection with the same cues with which it was learned. Memory is distinguished from cognition per se by the ability to recall information having once been exposed to the information. Memory storage, however, is an essential condition or determiner of cognition.

Divergent Production can be defined as the generation of new information from given information where the emphasis is on variety and quantity of output from the same source. Divergent production is related to creative imagination. In this process, items of information are retrieved from memory storage and used to generate a number of varied responses.

Convergent Production may be defined as the derivation of logical deductions or at least compelling inferences leading to a unique answer or conclusion. In convergent production the problem can be rigorously structured, and is so structured, and an answer is forthcoming without much hesitation.

Evaluation can be defined as a process of comparing a product of information with known information according to, logical criteria and making a decision concerning criteria satisfaction.

5.6.5 Human Limitations

The limits of human capabilities may be altered by both environmental and task related factors. Among the most commonly examined factors are atmospheric stresses - hostile changes in the individual's ambient breathing atmosphere. Six such stresses are identified in Table 2A. The severity of each stress is dependent upon both the intensity of the variation and the duration of the exposure. Each of the stresses indicated is capable of producing unconsciousness or death with the appropriate combination of duration and intensity.

In space operations, atmospheric stresses are generally compensated for by Environmental Control and Life Support Systems (ECLSS), either in the spacecraft or associated with the space suit during extravehicular activity. Because of this, atmospheric stresses do not commonly restrict activities, but they do add to the cost of utilizing humans in performing certain tasks.

The human also is susceptible to environmental stresses other than atmospheric and these stresses may also reach intensities that can produce injury or death. Stresses of the type indicated in Table 2B are not as easy to counteract as are the variations in atmospheric characteristics and are usually avoided by specific approaches to spacecraft design characteristics or mission operations.

The Space Adaptation Syndrome (SAS) or space motion sickness has occurred to some degree on all U.S. space flights since the days of the Mercury and Gemini Programs. In addition 49 percent of the Russian cosmonauts have reported the condition. The symptoms are generally the same as those associated with conventional motion sickness. They occur early in flight, peak at about 24 to 36 hours, but may last as long as four days.

The occurrence of SAS cannot be predicted in any given individual. Once adaptation has occurred in flight, however, and it always does, the individual is exceptionally resistant, even to challenging exposures, for the rest of the flight and for a week or more postflight.

The extent to which SAS degrades crew performance has not been measured with any accuracy or precision. There is some evidence that dedicated, well trained crew members will perform successfully despite the effects of SAS. On the other hand, some activities on previous space missions have been postponed or canceled because of SAS. Table 2C summarizes previous SAS experience on U.S. spaceflights. The SAS syndrome may mitigate to some extent the use of rapid response Trans-atmospheric Vehicles because of the critical nature of the first 24 to 48 hours in the weightlessness of space. Once adaptation to the space environment has occurred, however, longer duration missions associated with a space station or other manned and unmanned platforms have been demonstrated to be very feasible.

5.6.6 Potential Activities of Value

Human creativity and intellect, sensory and perceptual capabilities, and fine manipulative skills provide a valuable resource to draw upon in any application. While the human role in space can take many forms, it is suggested that Air Force planners seriously consider the use of humans to repair, service, and upgrade space systems. Assuming human access to space, considerable cost savings are possible by using humans to perform certain tasks in the deployment, servicing or upgrading of systems, even though operationally those systems may function as remotely controlled or monitored platforms. As an example, Skylab estimates (made in 1974 after the failure of the orbital workshop solar wing to deploy automatically) indicated that a manual deployment mode for the solar arrays would have produced a 15 percent weight savings in that system. In another NASA sponsored design study, a 25kw space platform[2] was designed to be a resource module to which unmanned pallets could be docked to receive power, cooling and other resources. This was similar in concept to the "motherboard" configuration described

2. McDonnell Douglas Astronautics Company, Alternative System Design Concept Study, NAS8-33955, July 1982

in the Air University's SPACECAST 2020 Study.[3] It was found that in the initial deployment some 15 different mechanisms including launch supports, solar array launch latches, radiator latches, antennas, etc. could be operated manually by an EVA crewman at an estimated EVA cost of $200K as compared to the development cost of $2406K required to provide automated or remotely actuated deployment mechanisms, a better than 10:1 cost savings.

Space crews are fully capable of performing such activities as: activate/initiate system operations; adjust/align elements; communicate information; confirm/verify procedures/schedules/operations; connect/disconnect electrical/fluid/mechanical interfaces; correlate data; deactivate/terminate system operation; deploy/retract appendages; inspect/observe; measure physical dimensions; perform precision manipulation of objects; engage in problem solving/decision making/data analysis; removal and replacement of modules/coverings; replacement and/or cleaning of surface coatings; transporting items from one location to another; etc.

At the present time NASA together with its international partners is developing an International Space Station (Space Station Alpha). Although this effort has been beset by many organizational changes and by budgetary and political constraints and has undergone a number of redesign efforts in the past five years, it is still scheduled to be built in orbit between 1997 and 2002 and to become fully operational at that time. It will operate at a 51.6 degree inclination in a low altitude (200-250 nmi) orbit. It will require 67 logistics missions during the building process, including 21 by the U.S. and the rest by Russia. After the Space Station becomes operational in 2002, NASA intends to phase out the current Space Shuttle and replace it with a new more efficient logistics carrier for transporting modules containing people and material to orbit. This will present an opportunity for the Air Force to consider the development of dedicated modules or work platforms providing the capabilities to remotely command, control, monitor, throughput, and preprocess data for free-flyers and other platforms, and to provide support capability for construction, assembly, and deployment of payloads. Payloads capable of maneuvering themselves within a reasonable distance of the space crews' work platform could be maintained, serviced and checked out. Payloads and satellites requiring transfer to other orbits could be integrated with a transfer stage and launched. The transfer stages could be commanded and controlled by the space crew and be either expendable or re-useable. Payloads, experimental samples, or captured samples requiring return to Earth could be demated, prepared, and stored until placed in the crew return module.

5.6.7 Man/Machine Trade Offs

The potential level of operational involvement of the human in any system falls somewhere along a continuum ranging from direct manual control or involvement at one extreme to merely monitoring systems that are self actuating, self healing, independent operations with minimal requirements for direct human intervention at the other extreme. For reference purposes several benchmarks along this continuum can be defined as summarized in Table 3.

The criteria that program managers and system engineers use to select the most cost effective approach to meet system objectives include performance, cost, and mission success probability. The decision maker must base his judgment on knowledge that a particular implementation option can or cannot meet the performance requirements in terms of such factors as force,

3. Air University, AETC USAF, SPACECAST 2020, Volume 1, June 1994

sensory discriminations, speed, and accuracy. If that option can meet the performance requirements, can it do so within the systems environmental constraints of, e.g. temperature, pressure, radiation, atmospheric constituents, mass limitations, and acceleration disturbance limits? In many cases, more than one implementation option can meet the performance requirements, and it is then necessary to examine the relative costs and the mission success probability in terms of the state of technological readiness or program confidence associated with each approach.

As experience is gained in manned space operations over the next 25 years the permanent presence of humans in space will be established. On the other hand, the competing demands on this Nation's limited economic resources are forcing an increasing awareness of the need to maximize economic efficiency in achieving the Air Force goals and objectives in promoting Global Presence, Global Reach, and Global Power. Baring a major worldwide confrontation the current DoD budget will likely continue to shrink in purchasing power. Furthermore future DoD space assets will undoubtedly be required to operate for longer lifetimes. If these assets are designed to be maintained, serviced, and upgraded in situ, and thereby allowing new technological advances to be introduced as they become available, it can be anticipated that the operational life of those assets can be significantly increased. This represents a direct analogy to today's environment where we find it cost effective to upgrade the systems in our current aircraft fleet even though some of the airframes themselves may be 30 years old.

In establishing the relative roles of the human in future systems cost will be a principal factor. Program planners and system designers must develop appropriate costing metrics to help in the decision process. One example of an approach to this process can be illustrated with data generated several years ago in a NASA sponsored study.[4] In the referenced study some 37 basic activities were derived from the analysis of the functions to be performed in a number of manned and remotely controlled space systems. The costs of performing these activities in manual, augmented, teleoperated, supervised, and independent modes of operation were derived, costs normalized, and nomographs prepared to define the domains wherein each man-machine node of operation would be most cost effective.

The human is limited in the number of activities that he can perform simultaneously in any given time interval and also in the number of times an activity can be repeated without fatigue setting in. These factors are key in the tradeoff decisions which must be made by the system designer in determining the mode of operation to be utilized in any given application. As an example, if an auto maker were to make a one of a kind model of a door assembly, it would be most cost effective to have that unit fabricated in the model shop with manual intensive labor. On the other hand in a production run of 500,000 or 1,000,000 door assemblies, labor costs would be so high that it would be more cost effective to invest in automated production equipment to manufacture the unit. The same reasoning applies to space systems. Even if an operation could be performed manually, if it must be repeated many times there is a cross over point where the cost of labor would dictate the use of some degree of augmentation or automation.

Figures 5.6.1, 5.6.2 and 5.6.3 are costing nomographs developed in Reference (1) to provide comparative data on the relative costs for each man-machine mode in performing from one to forty activities, from one to many thousands of times, as a function of the time (1, 10, 100

4. op. cit. (1)

minutes) required to complete the event. The relative costs of the various human/machine modes for the time intervals indicated are expressed in terms of normalized "Accounting Units". An accounting unit is defined as the cost to perform an activity one time in the manual mode.

In the man-machine modes requiring direct human involvement, the more activities that are required to accomplish a specific mission objective, the more time required and the higher the cost. In the modes where the human is more indirectly involved, the cost of resources and the supporting equipment items required to perform each activity in orbit contribute more to overall cost than does the time required to accomplish the activity. Thus, in modes requiring direct human involvement, the cost reduction due to the potential of sharing common equipment items and common resources can be a significant factor in the cost equation.

As an example of the use of these nomographs, if a particular task requires 10 different activities to be accomplished in 10 minutes or less, and will be repeated 200 times during the course of the mission, the most cost effective system design approach would most likely be to consider the use of teleoperators or other computer directed functions to perform the task. On the other hand, providing human support was available, if the task required only one activity to be performed during a ten minute interval the task would have to be repeated 100's of times before it would be cost effective to automate the process.

These examples are offered only to illustrate some of the factors involved in the design and operation of future systems. The point to be made is that as new systems are designed and old systems evolve. the Air Force must not arbitrarily abandon the human role in space to civilian agencies and to commercial entrepreneurs. In order to maintain a presence in space to serve those functions unique to our national security in a cost effective manner, manned military operations in space may be required and must be considered.

5.6.8 Conclusions

We have learned from the U.S. Space Programs to date as well as from the former Soviet Union that: (1) systems can have indefinite operational lifetimes in space if they are designed to permit the contingency of in-flight repair and maintenance; (2) structures too large to be launched intact can be constructed and assembled in orbit using the humans unique abilities; and (3) the flexibility and creative insights provided by the crew in situ significantly enhance the probability of achieving mission objectives.

The ability of the human to manually assemble delicate instruments and components and to remove protective devices such as covers , lens caps, etc., means that less rugged instruments can be used compared to those formerly required to survive the high launch-acceleration loads of unmanned launched vehicles. As a result the complex mechanisms secondary to the main purpose of the instrument will no longer need to be installed to remove peripheral protective devices or to activate and calibrate the instruments remotely. The time required to calibrate and align instruments directly can be as little as 1/40th of that required to do the same job by telemetry from a remote location. In general, physical articulation and movement constraints in teleoperated systems result in performance times that are up to ten times longer than if the same tasks could be performed by human operators.

The human can abstract data from various sources and can combine multiple sensory inputs (e.g., visual, auditory. tactile) to interpret, understand, and take appropriate action, when

required. In some cases the human perceptual abilities permit signals below noise levels to be detected. The human can react selectively to a large number of possible variables and can respond to dynamically changing situations. The human can operate in the absence of complete information. The human can perform a broad spectrum of manual movement patterns, from gross positioning actions to highly refined adjustments and in this sense behaves as a variable gain servo system.

For the foreseeable future, humans will continue to surpass machines in their perceptual abilities to recognize and interpret patterns of light and sound, improvise and use flexible procedures, recall relevant facts at appropriate times, reason inductively, and exercise judgment. On the other hand machines surpass humans in their ability to respond rapidly to control signals, apply great force smoothly and precisely, perform routine repetitive tasks reliably, store information and erase completely, process data deductively, compute complex relationships, and handle many different tasks at the same time.

With the advent of manned platforms in space inherent there are alternatives to potential deployment of remotely manned systems, with their operational complexity and high cost of system failure. Long-term repetitive functions, routine computations or operations, and large scale data-processing functions will be capable of being checked out, modified, and serviced by crews in orbit, just as they are now serviced in ground installations.

To date, NASA has developed many of the basic tools and techniques required to support intravehicular and extravehicular manned space operations. This available background of technology provides a point of departure for re-examining the role of the human in future Air Force applications. The Air Force infrastructure must be prepared, when appropriate, to utilize manned space capabilities in future mission applications

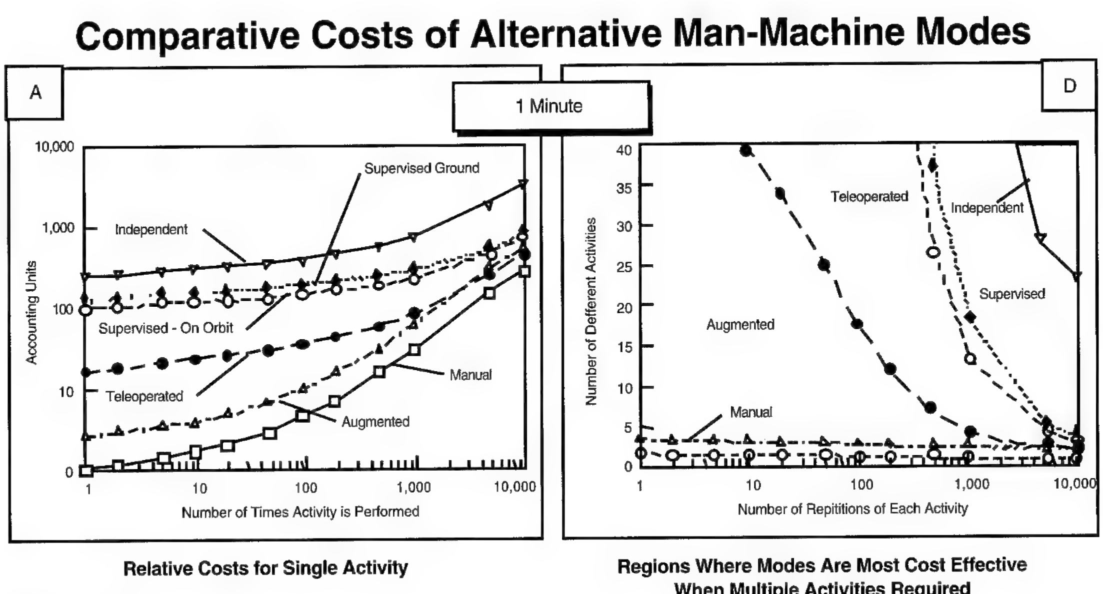
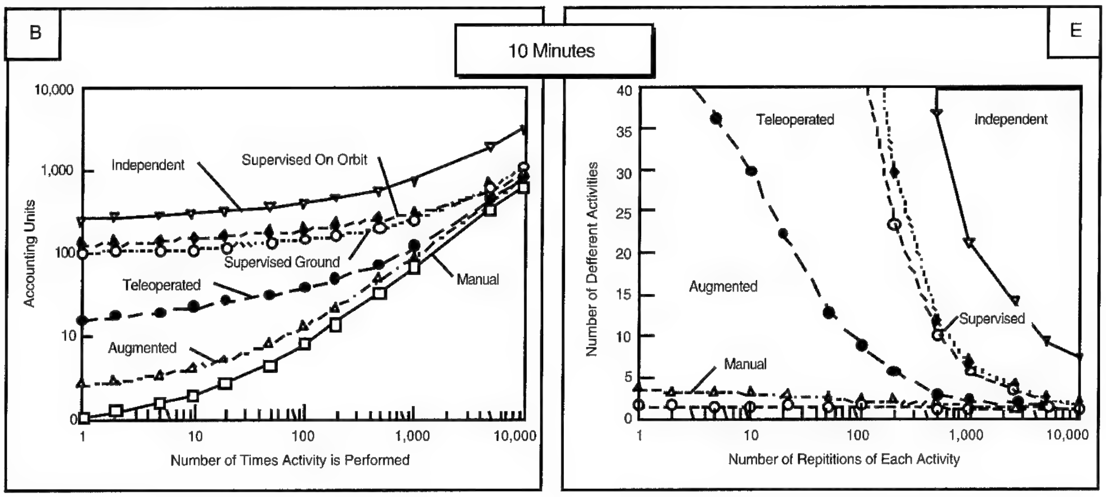


Figure 5.6.1

Comparative Costs of Alternative Man-Machine Modes (Cont)

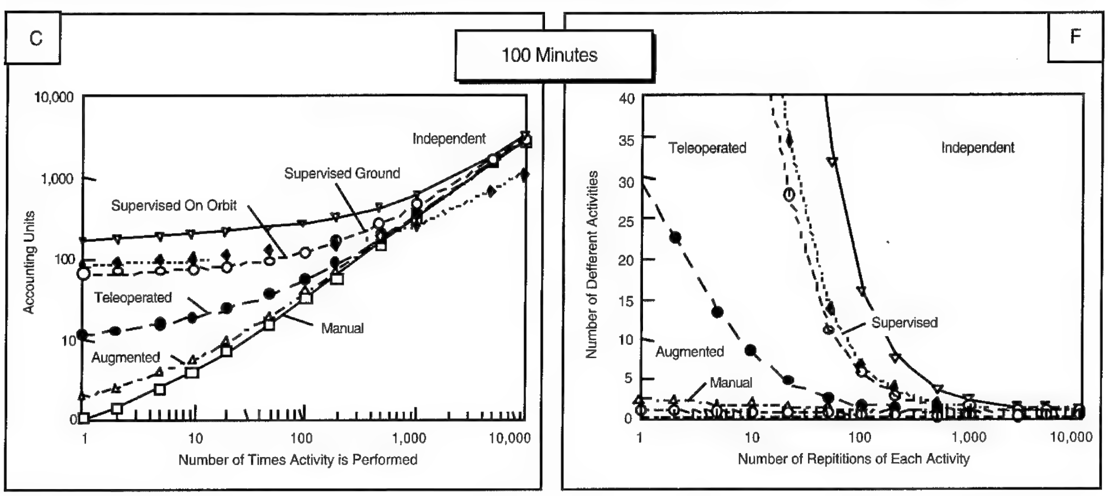


Relative Costs for Single Activity

Regions Where Modes Are Most Cost Effective When Multiple Activities Required

Figure 5.6.2

Comparative Costs of Alternative Man-Machine Modes (Cont)



Relative Costs for Single Activity

Regions Where Modes Are Most Cost Effective When Multiple Activities Required

Figure 5.6.3

Table 5.6.1

TYPICAL BASIC HUMAN CAPABILITIES

Sensory/Perceptual

- Visual Acuity
- Brightness Detection and Discrimination
- Color Discrimination
- Depth Perception and Discrimination
- Peripheral Visual Detection and Discrimination
- Visual Accommodation
- Detection and Discrimination of Tones
- Discrimination of Sound Intensities
- Sound Localization
- Tactile Discrimination of Shape and Texture
- Discrimination of Force Against Limb
- Discrimination of Limb Movement and Location
- Detection and Discrimination of Angular Acceleration
- Detection and Discrimination of Vibration
- Detection of Heat and Cold
- Detection and Discrimination of Odors

Intellectual

- Cognition
- Memory
- Divergent Production
- Convergent Production
- Evaluation

Psychomotor/Motor

- Production and Application of Force
- Control of Speed of Motion
- Control of Voluntary Responses
- Continuous Adjustment Control (Tracking)
- Arm/Hand/Finger Manipulation
- Body Positioning

Table 5.6.2

LIMITING FACTORS ON HUMAN PERFORMANCE

A. EFFECTS OF ATMOSPHERIC STRESSES

Type of Stress	Performance Degrading	Injurious or Life Threatening
Decreased Oxygen (Hypoxia)	Partial Press. Oxygen < 109 mm Hg	Partial Press. Oxygen < 73mm Hg
Increased Oxygen (Oxygen toxicity)	Partial Press. Oxygen > 400 mm Hg	Partial Press. Oxygen > 1500 mm Hg
Increased CO2 (Hypercapnia)	Partial Press. CO2 > 20 mm Hg	Partial Press. CO2 > 45mm Hg
Increased Temperature (Hyperthermia)	> 95 deg. F.	> 120 deg. F
Decreased Temperature (Hypothermia)	< 50 deg. F.	< 39 deg. F
Atmospheric Contamination (e.g. CO)	>25ppm CO	>400ppm CO

B. EFFECTS OF OTHER ENVIRONMENTAL STRESSES

Type of Stress	Performance Degrading	Injurious or Life Threatening
Vibration	0.08 g's at approx.4-8 Hz	2 g's at 3-8 Hz
Noise	80-85 dB	100-120 dB
Gz Acceleration	2 to 3 g's	5 to 6 g's
Gx Acceleration	5 to 6 g's	12 to 15 g's
Light	Complex	2.4×10^5 lumens/sq.ft.
Ionizing Radiation	---	>5 rads/day

Table 5.6.2 Continued

C. EFFECT OF SPACE ADAPTATION SYNDROME

	Duration of Exposure (hours)						
Human Capabilities Impacted	≤3	3-12	12-24	24-48	48-72	72-96	≥96
Vision	None	Mod.	Mod.	Negl.	Negl.	None	None
Discrimination	None	Mod.	Mod,	Negl.	Negl.	None	None
Discrimination of Angular Accel.	Negl.	Mod.	Sig.	Sig.	Sig.	Sig.	Sig.
Cognition	None	Mod.	Sig.	Sig.	Mod.	Negl.	None
Memory	None	Negl.	Negl.	None	None	None	None
Evaluation	None	Mod.	Sig.	Mod.	Negl.	None	None
Visual-Motor Tracking	Mod.	Sig.	Sig.	Mod.	Negl.	Negl.	None
Manipulative Skills	None	Mod.	Sig.	Sig.	Mod.	Negl.	None
Body Positioning	Mod.	Sig.	Sig.	Mod.	Mod.	Negl.	None

None = (None) Negl. = (Negligible) Mod. = (Moderate) Sig. = (Significant)

Table 5.6.3 **CATEGORIES OF HUMAN-MACHINE INTERACTION**

Manual
Unaided manual activities possibly requiring the use of simple tools or restraints.

Augmented
Amplification of human sensory or motor capabilities with powered tools, exo-skeletons, sensing devices, etc.

Teleoperated
Use of remotely controlled sensors and actuators allowing the human presence to be removed from the work site: e.g., remote manipulator systems, teleoperators, telefactors, etc.

Supervised
Replacement of direct manual control of system operation with computer-directed functions although maintaining humans in supervisory control.

Independent
Self-actuating, self-healing, self-learning, independent operations dependent on automation and artificial intelligence, and minimizing the requirement for direct human intervention.

5.7 Modeling, Simulation and Analysis

Christopher Waln

Modeling, Simulation and Analysis of space capabilities and the integration of those capabilities into terrestrial operations and the overall force structure is extremely partitioned. MS&A are partitioned by classification, by mission area, by space vs. terrestrial, and by government vs. industry proprietary. This partitioning has evolved from the Cold War concepts of space systems management and space force employment. This situation is antithetical to advancing the application of space capabilities to joint warfighting.

The SDIO, through its National Test Bed, spearheaded the concept of interlinked MS&A which could be used to demonstrate technical and operational concepts well before substantial hardware investments were necessary. The concept did not deliver the envisioned benefits because of changes in national policy on missile defense. Since then, the state of the art has out-paced the National Test Facility (NTF) implementation, but the concept remains valid.

The concept was extended by Air Force Space Command (AFSPC) and Air Force Material Command (AFMC) in its "Seven Strategies for Space" to include all stakeholders in space—military, Intel, civil, and commercial. The concept was expanded to include the ability to support decision making through experiments, demonstrations, and exercises with technology, hardware, and humans in the loop. The concept, for management purposes, was named Frontier Arena and early demonstration recommendations focused on exercise support in much the same way the NTF is currently supporting joint exercises. The next level of implementation will be to provide support to DoD level space modernization decision-making by enabling warfighter in the loop assessments of alternative architectures.

Ultimately, Frontier Arena may be used to evaluate tactics, operations, and strategies involving the integration of space and terrestrial capabilities. By linking the various space and terrestrial MS&A capabilities in a shared ownership environment where each of the stakeholders can take advantage of the whole (given security and contracting limitations) the partitioning will be gradually eliminated and we will be well on our way to thinking about space as an integral element of our military forces rather than a stand-alone appliqué.

Frontier Arena or something like it is essential to maturing our thinking about space and space related terrestrial issues. Current net assessment models either assume space assets (their products actually) are universally available and have attributes undifferentiated from terrestrial assets. For example DoD level net assessment models do not distinguish the presence or absence of space based weather support; they assume perfect positioning awareness and cannot assess GPS degradation; they assume communications and "monte carlo" availability on the basis of enemy capabilities to interfere without regard to the means of communication; and early warning information is drawn from "look-up" Tables. This is not a pejorative assessment of the mode but an indicator of the immature state of our ability to fully exploit space and space assets.

Beyond Frontier Arena, virtual reality implementations offer the opportunity for political leaders and warfighters to visualize the interaction of all force elements—lethal and otherwise. Within the horizon of New World Vistas it will be possible for military officers and their civilian leaders to stand in the middle of a virtual theater and conduct digital sand-table maneuvers in multiple dimensions--space, time, and consequences. War rooms will not only contain the order

of battle for the forces arrayed against one another but the other elements of national power as well. Commanders will be able to design there operations, test them, deploy the orders to the forces, and evaluate the results and required changes in one continuous intuitively visualized environment. Such a concept will put us inside our adversaries political, military, and economic turning circles for decades to come.

The Air Force plan for the joint implementation of Frontier Arena is fundamentally sound. It represents the first step on a path to command situation awareness previously only in the province of the futurist or science fiction writer. The Air Force is particularly well suited to lead such an enterprise and should commit to do so on behalf of the Department of Defense.

6.0 Conclusions and Recommendations

A general assessment of the future world environment and technological developments leads to conclusions and related recommendations for action by the United States Air Force. The recommendations are provided in the context and on the assumption that the Air Force will be the executive agent for DoD space matters and that the Air Force is prepared to assume the responsibility of supporting all military customers and national needs as required by the National Command Authority.

The overarching conclusions are:

- Successful integration of space with our information based warfare capabilities will be critical to maintaining information dominance of the battle space and winning at information warfare;
- The proliferation of commercial space systems gives our adversaries unprecedented access to militarily significant capabilities that will reduce the information advantage our forces presently enjoy;
- The Air Force must welcome and capitalize on capability growth and technological advances in commercial space in the fielding of militarily useful systems;
- The need to disrupt, deny and influence the enemy's perception of the battle space while assuring our use for information based warfare is essential, and thus space control takes on new significance in this environment;
- In the long term space systems will be well suited to project force from space to targets anywhere on earth;
- Some near term program activities could limit efficient implementation of the future options envisioned in this report, and the Air Force should establish roadmaps to correct this situation.

The Space Application Panel arrived at the following specific conclusions and recommendations:

Information Warfare

With the proliferation of commercial information sources the management of information and influence of the enemy's perception of the battle space through information warfare will be the dominant factor in deterring and winning future wars. Collection, fusion, analysis, disruption, disablement, denial and tactical and strategic deception of battlefield awareness are warfighter functions that must be integrated into our joint warfare operations to attain and maintain information dominance.

Recommendations

1. The Air Force should support integrated but dispersed processing and fusing of intelligence and battlefield awareness data to provide our forces the advantage of faster and more expert use of available information.

2. The Air Force should advocate the creation of a joint warfare information function to be in charge of all information that influences the outcome of the battle.

3. The Air Force should take the lead to define the space system requirements to support offensive and defensive information warfare.

Commercialization

Capability growth and technological advances in commercial space, especially communications, positioning, environmental monitoring and reconnaissance will far outpace government efforts in many areas. Customers, including individuals, corporations and nations, will have unprecedented access to militarily significant data that will reduce the "information advantage" our forces enjoy presently. These systems will be comparatively robust, secure and accessible as unique military systems.

Recommendations

1. The Air Force should develop specific road maps for the exploitation of commercial communications, positioning, environmental and reconnaissance systems that assure availability of these assets from day to day peacetime operations through major regional conflicts.

2. The DoD must develop, document and implement an approach to positively incentivize commercial providers of space-based goods and services to do business with the government and to add military-unique functionality to their commercial systems to give the DoD incremental advantage at lowest costs. The key is to establish relationships with commercial providers early in their development cycle.

3. The Air Force representing DoD should establish an integrated product team to: a) maintain a continuous assessment capability of commercial space systems and their supporting communications and ground infrastructures which may be potentially useful or threatening to the United Sates; b) act, or enable a clear path to higher authority to recommend action, as a result of these assessments; and c) infuse commercial technology/operational capability awareness throughout the relevant planning, acquisition and operational elements of the USAF.

4. The Air Force, representing the DoD, should establish much more effective mechanisms to promote regular dialog, alliances, and investment to interact/participate with US commercial space enterprises in the areas of: a) standards definition, b) bandwidth/frequency allocation, c) joint specifications definition, d) joint development, especially for low-demand but cutting-edge technologies important to the US government, and e) operational control/access/privileges during times of declared national emergency.

Distributed Satellite Systems

Advances in computers, sensors, and materials permit establishment of large constellations of interlinked satellites, whose integrated output will give global, real-time coverage. Reducing range to target and constellation altitude reduces satellite size and cost of coverage. The advantages of such systems have already been embraced by the commercial space industry as the way ahead.

Recommendations

1. The Air Force should create a road map which recognizes the twin realities of inexpensive, single-sensor, small satellites and distributed processing and communications enables a significant advance in reconnaissance, surveillance and battle awareness.

2. The Air Force should begin development of a suite of small satellites to complement the evolving national sensors for timely battle field reconnaissance.

3. The Air Force should focus, where appropriate, on hybridized, distributed architectures, employing on-board processing, storage and cross-linking now being incorporated in commercial distributed space system designs.

Communications

Future multimedia communications systems will provide broadband communications to any person and to any point on the globe. These universal capabilities, whose transmission media and routing will be transparent to the users, will be available commercially and will provide reliability, flexibility, capacity, security and quality of service that will be difficult to match with government owned systems. Connections to other elements of the information systems may be more limiting than the communications systems themselves. Rapid expansion of use of available bandwidth due to advances in processing and antenna technology will significantly improve communications available to mobile users.

Recommendations

1. The Air Force should develop and implement a global terrestrial and satellite communications architecture whose infrastructure would be built upon both DoD and commercial capabilities.

2. Published standards should be established for future communications architectures to be distributed, flexible, scaleable, fault-tolerant, reconfigurable, and transparent to the users.

3. The Air Force should advocate the practice that DoD users who can reside on fiber optic arteries should be required to do so, and the warfighters given priority for satellite communications for mobile and tactical users.

4. Truly unique military survivable and enduring satellite communications requirements should be identified and implemented through a combination of unique military space systems, complemented with appropriate non-military systems and technologies.

Global Positioning , Time Transfer And Mapping

The current Global Positioning System (GPS) using the P(Y) code meets the basic requirements of the military for precise position location and time transfer. The GPS employs the Defense Mapping Agency WGS 84 world wide grid permitting maps and data, such as derived from reconnaissance, to be expressed in a common position language for use as needed by the warfighter. The GPS user receivers when properly designed and integrated with Inertial Measurement Units provide highly accurate navigation in three dimensions to fast moving vehicles. Such military receivers are resistant to jamming especially when equipped with self-nulling antennas. The C/A code is available to all GPS user receivers. It thus can be used by potential enemies unless jammed in the battle area. The use of the Selective Availability concept has reduced international acceptance of the GPS for such civilian uses as commercial air navigation and proliferation of differential GPS has diminished its usefulness.

Recommendations

1. The use by the DoD of selective availability (S/A) to reduce the accuracy of the C/A code position location should be discontinued.

2. Methods and systems should be developed to assure U. S. and allied forces positioning information over limited battle areas while denying similar quality support to the enemy forces without seriously affecting essential out of area civil and commercial operations.

3. In the long term the Air Force should aggressively support advanced technology using space systems leading to consistent positioning and mapping accuracies on the order of 30 centimeters. Such space systems should support relative position accuracies in the centimeter range.

4. Time transfer to accuracies of a nanosecond or less should be an integral part of any global positioning system to provide synchronization in future communications and information systems. The highly accurate temporal and spatial information should be assigned eventually to all information and serve as the basis for the storage and retrieval of this information.

Observation And Battlefield Awareness

The information that can be obtained from space-based sensors integrated with airborne systems and geopositioning capabilities offer the potential for revolutionary changes in the combat environment and employment of forces. Future U. S. commanders must have near real-time, all weather information on the location and status of friendly and hostile forces; locations of moving ground, sea and airborne vehicles, and space objects; current and future projections on terrain and weather; nearly instantaneous threat warnings; and the ability to share this information with all levels of command.

Recommendations

1. In order to exploit fully the available technology to the warfighter's advantage, the Air Force should be a full participant in planning, developing, acquiring, launching, and operating of U. S. military and intelligence space reconnaissance assets.

2. Aggressive investment should be continued on methods and technologies to extract information from data at all points of the process. The focus should be on rapid, smart systems to reduce the dependency on humans wherever appropriate.

3. A user-needs driven attitude should prevail within the information acquisition community and a seamless interface should be established with the intelligence community to ensure sharing of data bases, and commonality of objectives. System, and architecture definition and implementation with full warfighter input, recognizing the need for balance among all users, technology and attendant costs should be pursued.

Space Control

Because of the general recognition of the importance of space systems to successful combat, we must assume our space systems will be threatened and it will be necessary to limit an adversary's access to space capabilities. Survivability requirements and techniques,

against both hostile and natural threats, are as important for space system acquisition and operations as for terrestrial systems. A spectrum of offensive capabilities ranging from temporary disruption of hostile ground operations to satellite negation should be available to our forces. Local control of an enemy's environment, through disruption of his communications and information infrastructure, without global disruption will be an important tactic.

Recommendations

1. The Air Force must ensure that its most valuable space assets are safe against attack by third world nations, rogue groups and major powers.

2. The Air Force must develop and field a capability to deny, degrade, disrupt, exploit and, if necessary, destroy the use of space assets by others, globally or in a local region.

3. The Air Force should continue to study the potential threat posed by space debris and the necessary techniques for its surveillance, mitigation and removal, if necessary.

Force Projection

Future space systems will be well suited to project force against air, land and sea-based targets anywhere on earth. Precise delivery of munitions, directed energy or electronic warfare on virtually any target, heavily defended or not, within minutes or hours of tasking and with minimal risk to U. S. forces could have a decisive impact at all levels of conflict.

Recommendations

1. The Air Force should broaden the use of space to include direct force projection against surface, airborne, and space targets.

2. The Air Force should define and develop microwave and laser space-based weapons for tactical and strategic applications

3. The Air Force should develop space munitions capable of precision strikes against surface and airborne targets.

Access To Space

A number of commercial projects are underway to develop small and medium launch vehicles and there is strong competition from the international providers of large vehicles. Full integration of space capabilities into routine military operations will only be realized when launch is no longer a significant operational constraint. Although expendable vehicles may continue to provide limited, unique services, over time, dramatic improvements in cost and capability will come through an operational reusable system for all orbital regimes. The same technologies and operational concepts needed for reusable space launch will support transatmospheric systems that could provide presence anywhere on the globe in under two hours. Military human roles in space may evolve in time for on-orbit support of complex systems.

Recommendations

1. Continue to support the NASA reusable space launch technology efforts within the Air Force laboratories including the X-33 technology efforts but emphasize operability and reliability.

2. Continue to support a hypersonic technology development program with the objective of readying the technology base to support the development of future transatmospheric vehicles.

3. In conjunction with NASA continue to investigate the utility of humans in space for military operations.

4. Place emphasis on developing high specific impulse, high thrust propulsion technology to support development of future launch and orbital transfer vehicles.

Modeling, Simulation, And Analysis

Modern and future tools for connecting widely distributed centers of MS&A excellence and the explosive growth of virtual reality concepts and technologies will make it possible to conceive ideas and test them with technology, hardware and humans in the loop and then smoothly transition these experiments, demonstrations, and exercises into operations with unprecedented speed at heretofore unrealizably low costs. This is particularly true for the utilization of space systems. The Air Force should exploit these opportunities and the substantial investments in the National Test Bed to underwrite the development of doctrine, lower the costs of modernization, and train the joint warfighter.

Recommendations

1. The Air Force should quickly press ahead with a joint implementation of a DoD "virtual test bed" for space technical concepts and warfighting conops.

2. The DoD must eliminate the boundaries between MS&A for modernization support and MS&A for operations support. A seamless process which includes the joint warfighter in acquisition MS&A and the acquirer in operations support MS&A will be essential for rapid and cost effective reconfiguration of systems of space systems.

3. The Air Force, in conjunction with the Army, Navy, Marines, and others, should exploit virtual reality implementations to make space support more readily understandable to the political decision maker and the warfighter by allowing individuals to immerse themselves in the space-terrestrial operations continuum.

Appendix A

Panel Charter

- Define space applications which enhance the intrinsic capabilities of the Air Force.
- Project system concepts and operations that will offer fundamental improvements and reduce costs in military operations.
- Identify those areas which will most likely revolutionize the 21st century Air Force.
- Consider the use of commercial and international space systems to support military operations and the impact on United States security from proliferating technology
- Recognize the Air Force responsibility to support warfighting as well as national customers and integrate operations with other services and agencies.

Appendix B

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Appendix C

Panel Meeting Locations and Topics

15-17 March Peterson AFB, Co

- Roles and Missions, Launch Vehicles, Warfighter Support, GPS, TENCAP

12 April ANSER Corporation, Washington DC

- Army Warfighter Requirements, Army Positioning Needs, Naval Space Requirements, Weather

3-5 May Maxwell AFB, AL

- Air Force Revolutionary Planning Process, SPACECAST 2020

21-23 June The Aerospace Corporation, CA

- Launch Vehicles, Small Satellites, Commercial Systems, Spacecraft Vulnerability

Appendix D

List ofAcronyms

Acronym	Definition
ATH	Above The Horizon
AVHRR	Advanced Very High Resolution Radar
BDA	Bomb Damage Assessment
BMD	Ballistic Missile Defense
BSTS	Boost Surveillance and Tracking System
BTH	Below The Horizon
CDMA	Code Division Multiple Access
CW	Continuous Wave
DARO	Defense Airborne Recce Organization
DRB	Defense Resource Board
DSP	Defense Support Program
EHF	Extremely High Frequency
ELINT	Electronic Intelligence
ELV	Expendable Launch Vehicle
EOS	Earth Observing System
ERP	Effective Radiated Power
ESA	European Space Agency
FEWS	Follow-On Early Warning System
GBPS	Gigabytes Per Second
GEO	Geosynchronous Earth Orbit
GPALS	Global Protection Against Limited Strike System
GSD	Ground Sampling Distance
GSI	Gigascale Integration
GTO	Geo Transfer Orbit
HEO	High Earth Orbit
HLV	Heavy Lift Vehicle

HUMINT	Human Intelligence
IMINT	Imagery Intelligence
ITU	Inter. Communications Union
IUS	Inertial Upper Stage
JTAGS	(Joint Tactical Air/Ground System)
LDI	Long Dwell Imaging
LEO	Low Earth Orbit
LOC	Lines Of Communications
MLV	Medium Lift Vehicle
MSTI	Miniature Sensor Technology Integration
MWIR	Mid Wave Infrared
NASP	National Aerospace Plane
NIIRS	Near Imaging Infrared Systems
NMD	National Missile Defense
NPIO	National Photo Interpretation Office
NRO	National Reconnaissance Office
NRP	National Reconnaissance Program
OB	Order Of Battle
OSTP	Office of Science and Technology Policy
PBV	Primary Booster Vehicle
RISC	Reduced Instruction Set Computer
SA	Selective Availability
SAMP	Single Acquisition and Management Plan
SAR	Synthetic Aperture Radar
SATCOM	Satellite Communications
SBI	Space Based Interceptor
SBIRS	Spaced Based Infrared System
SED	Sensor Evolutionary Development
SHF	Super High Frequency
SOSI	Space Object Surveillance and Identification
SOSS	Soviet Ocean Surveillance System

SPS	Standard Positioning System
SSTO	Single Stage To Orbit
SSTS	Space Surveillance and Tracking System
STG	Science and Technology Group
SWIR	Short Wave Infrared
TMD	Theater Missile Defense
UE	User Equipment
UHF	Ultra High Frequency
UTC	Universal Time Coordinated
WGS	World Geodetic Service

Appendix E

Bibliography of Briefings Received

15-17 March Peterson AFB

AF TENCAP Briefing to NWV Space Applications Panel
Space Warfare Center

DSB Task Force on GPS—Final Briefing
W. Delaney and S. Koonin
MIT Lincoln Lab

Global Presence 95
Department of the Air Force

Launch Vehicle Technology Perspective
Gareth D. Flora

NWV Overview Briefing
Scientific Advisory Board Secretariat

NWV Space Applications Panel Terms of Reference

Providing Space Support to the Warfighter
Dr. Yarymovych
Rockwell

Roles and Missions of US Space Force
Lowell Wood

Spacecraft Technology: In Support of a New Reality
Martin-Marietta

Tech Report to Secretary of Transportation on National Approach to Augmented GPS
NTIA Special Publication 94-30

12 April ANSER Corporation

Army Geospatial Requirements
Lt Gen D. Maxon
Dep Chief of Staff for Intelligence

Army TENCAP into 21st Century
Army Space Program Office

Army Warfighter Requirements
Maj Gen J. Ellerson
Office of Chief of Staff for Ops and Plans

Evolving From Space Support to the Warfighter
Col H. M. Ward
DCS Plans and Ops, HQ USAF

Meeting Naval Requirements Through Space
RADM Kathy Laughton
Commander Naval Space Command

Owning the Weather
R. Szymber and J. Cogan
Army Research Lab, White Sands

3-5 May Maxwell AFB

AF Revolutionary Planning Process
Lt Gen J. Ralston
Dep Chief of Staff, Plans and Ops

SpaceCast 2020
Air University, Maxwell AFB

21-23 June Aerospace Corporation

Advanced Space Technology for 21st Century
A. Sutay
Boeing Defense and Space Corporation

Assessing SSTO Feasibility
Lt Col J. Sponable
Phillips Lab

Hughes Brief to SAB Space Applications Panel
T. Bracky, S. Rosen, M. Schusene, C. Hoff

Hyperspectral Imaging Systems
Dr. T. Krabach
JPL

Interim Report by Ad Hoc Committed on Space Surveillance, Debris and NEOs
Dr. Greg Canavan

Internationalization of Space Technology
D. Lewis
Aerospace Corporation

Overview of Rockwell's RLF Concept and Supporting Technology
T. Healy
Rockwell

Planning for Future Space: Context and Opportunities
Col B. Preston
SMC/XRT

Rest of the World Potential for ASAT Technology
A. Johnson
Rockwell

Reusable Launch Vehicle Technology
Lt Col J. Sponable
Phillips Lab

Satellite Vulnerability: A Post Cold War Issue?
A. Thompson
Space Policy, Feb 95

Second Generation Micro-spacecraft
D. H. Collins
JPL
California Institute of Tech

Single Stage Rocket Technology: Fast Track Acquisition
Lt Col J. Sponable
Phillips Lab

Status Report from Center for Space Microelectronics
Briefing to Aerospace Board of Directors

Tactical Imaging Constellation and Architecture Study
Col P. Rustan
NRO

Teledesic Global Wireless Broadband Network: Space Segment
J. Stuart
Teledesic Corporation

Why SSTO Launch Vehicles Are Now Feasible and Practical
Ivan Bekey
NASA Headquarters

Appendix F

Contributed White Papers

(Arranged Alphabetically by Organization)

National Media Laboratory
Dr. William Mularie

- The Coming Flood: The Challenge of Information Management in the DoD

SAIC
Maj Gen Robert Rosenberg, Ret.

- Future Military Space Systems and the Principles of War

SAIC
Maj. Gen. Robert Rosenberg, Ret.

- Possibilities for the Use of Current and Emerging Technologies to Enhance Future Warfighting Capabilities Using Space Systems

The Coming Flood:
The Challenge of Information Management in the DoD

Dr. William Mularie

Introduction

New technologies are traditionally viewed only in terms of what they will *do* and not in terms of what they will *undo*.[1] Dr. Edward Teller at a recent SAB meeting at Maxwell AFB, asked the questions (paraphrased), *"With a thousand-fold increase of data and information to the command structure-Who makes the decisions? How are they made?"* The current explosion in information technologies, driven by the power and ubiquity of computer & communications architectures, will severely stress the DoD command and control structures unless the nature and scope of the problems that it will generate are recognized and addressed.

I. Who is in Charge?

Bureaucratic structures have traditionally held their power by their ability to control and manage information. The downward flow of processed information to each level of the organization was only that subset necessary for decisions and control to be exercised at that level. The disruptive impact of the information revolution upon traditional government and corporate structures is now being played out. For example, world governments and central bankers now recognize that the monetary structures that they envisaged to control the boom and bust cycles of global economies, for example the Bretton Woods agreement of 1948, are now dysfunctional. The relative value of world currencies are now controlled by market traders who employ mathematicians and physicists to build computer-driven mathematical models and communications channels to move $$ Trillions daily. These models, for illustration, instantaneously relate the movement of futures oil contracts on the Singapore exchange to, say, the value of the Spanish peseta options[2] The current realization is that attempts at bureaucratic control of information in is now essentially futile. The "flattening" of business organizations and the "empowerment" of employees throughout the business structures is largely the result of the ubiquity of information flowing throughout all levels of the corporation through computer information channels[3]. The conundrum that traditional corporations face is that, in the new world of equal access to information throughout organizational levels, the traditional hierarchical, information-based, decision-making tree, is no longer relevant. Thus, the source of power and control in current corporate structures is principally budgetary.

The DoD is replicating the commercial drive to build the high bandwidth communications channels((from T1(1.5 Mbps) to Sonet OC-12(622Mbps)) to allow extraordinary data flow throughout the command structure. What is the form and function of the future of the DoD command and control structure, when information in a massively parallel manner is available instantaneously at all levels of the command structure? For example, what is the effect of the direct downlinking of imagery and other sensor data to the field commander (increasingly from commercial providers outside the control of the DoD), and the ability of the warfighter to communicate globally outside the DISN channels, with low cost, personal PCS devices via Iridium, Spaceways and other high bandwidth commercial channels? In this new world, who in the command and control structure has the best, most timely information? Who makes the decisions? Is the concept of "empowerment" consistent with military practices? Further, even if we

can satisfactorily develop a construct which deals with the new information access realities in the command and control structures for current amounts of information, consider the impact of the coming flood of 1000x in the received data and information in the next decade.

II. Information: The "Garbage" of our New Age:

Neil Postman[1] argues in his book, *Technopoly: The Surrender of Culture to Technology* that: "there are very few political, social or personal problems that arise because of insufficient information," and, "information now appears indiscriminately directed at no one on particular, in enormous volume--disconnected from theory, meaning or purpose." Man, in this information technology age, becomes merely an information processor, relieved of making decisions based upon the traditional process of using his experience, intuition and insight. We are like the residents of the garbage dumps of Manila, picking around in increasing mounds of refuse trying to glean those tiny bits of material that will sustain us. On the Internet we employ surrogate agents to search the overburden for us with the unlikely names of "Vernonica" and "Yahoo"--the latter probably reflecting the sheer joy of finding any useful information. One is also struck by dulling effect of the enormous traffic burdening the network, limiting access to the needed information.

III. The Conundrum: Man and Machine:

The fear is that the gridlock that we have created in the civilian world will be replicated in the DoD structure because the seeds of the problem lie within us:

- Our importance scales in a monotonic way with the amount of information to which we access, collect or process
- We hoard, revere and give information expensive places to dwell—whether the libraries of the Medici or the magneto-optical, holographic or magnetic storage devices populating our systems
- We never question the current or future value of our information hoard (consider what valueless, expired information lies on our hard drives or in our file cabinets), and
- What we *need* to access is effectively hidden by the overburden of what we will *never need*

Computer technology and networks are the insidious enablers of our destructive tendencies. Our current experience allows us to project the following scaling laws for future DoD computer networks:

- The available storage capacity and bandwidth will be oversubscribed, independent of the network capacity and bandwidth
- "Requirements" and technology will develop bandwidth-intensive applications that will bring any network to it's knees. Excess bandwidth is an anathema to users and applications developers (the parallel of "nature abhors a vacuum"), and
- Non-critical (unimportant, time-insensitive) requests will represent 99% of traffic on network (e.g, downloading video clips or TIFF images of the Playmate of the Month)

IV. Rethinking our Information Systems:

Admiral William Studeman, former Deputy Director of the CIA, described the three levels of activity as organizations attempt to deal with new realities:

- **Relabeling** - continue on present course under a different banner
- **Restructuring** - continue on present course with a new, politically correct organization chart, and
- **Rethinking** - the most difficult but most necessary exercise to deal with new realities-questioning current doctrine and creating new structures and cultures to deal with new problems

In **rethinking**, some areas to be addressed include:

1. **Information Control**
2. **Bitway Architecture Control, and**
3. **Things We Don't Control (but must utilize)**

The latter recognizes the commercial capabilities, such as Direct Broadcast Satellite (DBS), available in the electromagnetic "ether" that surrounds the DoD structures from the JCS to the shooter. These commercial *technologies* are currently being tested and integrated into the DoD planning process for communications architectures. Less visible is the attempt is invest in and *use commercial platforms to carry the bits*. Replication of commercial systems for the sole use of the DoD addresses only 1/2 the commercial benefit—that of obtaining state of the art technologies. It does not mitigate the huge DoD investments required to emulate commercial performance, nor does it satisfy the investment rationale: the provision for "assured access, security and robustness." The massive parallelism of global commercial broadband communications systems yields a robustness that exceeds that of defense systems, where single point of failures are inherent in the designs. Network security using simple public key encryption schemes provide data integrity even in unbounded networks. But let us focus on the former two areas:

1. Information Control:

According to Postman(1), there are three interrelated methods by which society controls the flow of information:

- **Bureaucracy** - which he describes as a "coordinated series of techniques for reducing the amount of information that needs processing"
- **Expertise** - the expert concentrates on one field of knowledge and determines what information to use in solving a problem and what to ignore, and
- **Technical Machinery** - reduce the types and quantity of information admitted into a system

Within these methods of information control we recognize some general principles that should be adopted to prevent the replication of the current civilian chaos to the emerging DoD information systems. DoD information systems design must be designed to keep the experts and expert systems in the information channel to:

- Provide value-added insight (expertise), and
- To provide "natural" compression (data to knowledge)

Expert exploitation (the process of converting data and information into knowledge) of, for example, specialized sensor data, is critical. For example, the task of rapidly and accurately deciding whether signals from diverse sensors signals, such as those looking for an enemy missile launch, can only be done by imbedding experts in the data stream , using their experience and total knowledge of the system. Having access to the same signal data in a tactical field situation does not yield the same result and could have catastrophic international consequences.

Data compression is viewed as applying mathematical transforms to allow stuffing more data bits through a communications channel. Man, in the information channel, has a much more powerful influence in assimilating and reducing large, disparate data sets into higher level languages (e.g., "yes", "no",...)

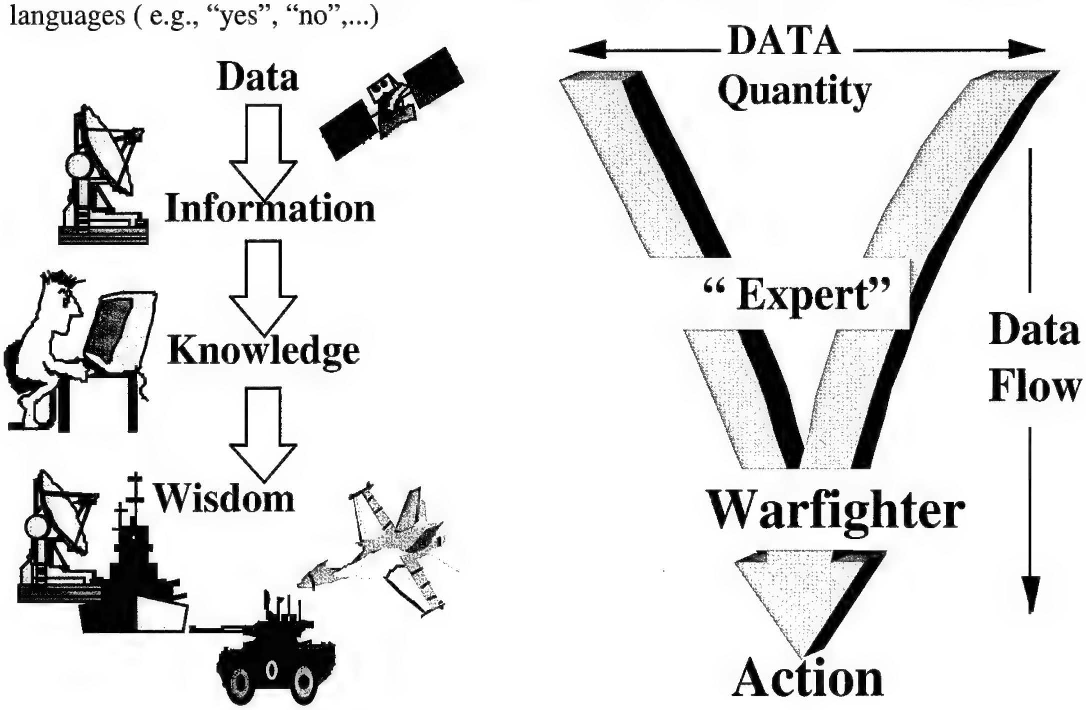

Figure F-1. ***The Dark Side of the Current Communications Push: The Concern***

Technology evolution in the DoD and commercial markets has given the DoD the ability to transmit to the field those sensor data (imagery, signals intelligence) and processing tools which were once the domain of the experts. Instantaneous, parallel delivery of sensor data to all levels of the military structure, as illustrated in Figure F- 2, raises the concern voiced by Dr. Teller: "Where are the decisions made?, Who has the best information ? Additionally, if one overlays this picture with a 1000x increase raw data bits, the problem becomes untractable."

However, the *reasons* for circumventing these expert nodes in the information chain should be carefully examined in light of the above consequences of information chaos.

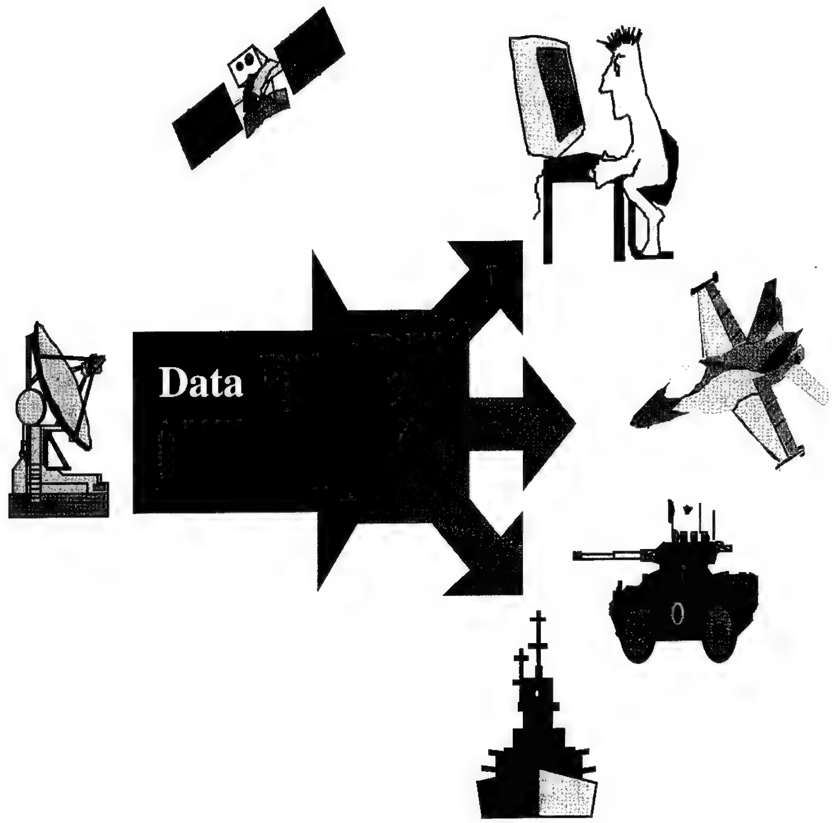

Figure F-2. The Coming Age: Every " Bit" to Everyone

2. "Bitway" Architecture Control:

Communications architectures must be designed from the *user needs upward*, rather than from the content providers (Imagery, Mapping,...) or engineering offices downward. This statement appears obvious, but I would point out the commercial failure of Video-on-Demand (VOD) where ostensibly market and technology-wise corporations wasted hundreds of $millions. They had assumed, through engineering studies and "customer" surveys, that the technology and consumer demand was present to deliver video into the home in a instantaneous fashion, keeping the ability to keep the VHS tricks (stop, start, rewind...). They were wrong on both counts, at great cost.

Lastly, information management requires that DoD architects optimally parse information types among the available DoD and commercial "bitways". Information varies in criticality, timeliness, security, file size, origin and destination, to fixed or mobile commands, etc. "Bitways" vary in their capacity, availability, robustness, geographic reach, interface requirements. This is an "m x nî, where the variables are time dependent. This problem that requires knowledge and close cooperation with US commercial entities to ensure the access, capacity, security and robustness to carry the DoD in this new information age.

Conclusion:

Organizations, in the rush to incorporate new technology, must consider and reconcile the negative as well as the positive impacts of technology insertion. Critical to the planning process is the need to negotiate the role of the human in the new technology paradigm. This paper argues specifically that the DoD, in the design of its information architecture (meaning hardware and systems), must also construct a *user* architecture (meaning, determining the appropriate (what, where, when) information needed by the decision makers in the system) to allow military operations to flow quickly and accurately from raw sensor data to force application.

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Future Military Space Systems and The Principles of War

Robert Rosenberg

Introduction

The world is a rapidly changing place--a place with continuously disruptive impact on even the best military planners' approaches to the architecture of our military forces. Without well founded underpinnings for our military force architecture, force structure and training, we often are accused of preparing for the next war by designing to refight the last one. For this reason it is instructive to return to first principles when we examine the needs for our space architecture of the future. As the race of technology unquestionably establishes space as a future theater of war, it is important that we build an architectural foundation for space which draws on the principles of war. These principles have been stable over the ages, changing only in their implementation through technology rather than their fundamental thrust.

Regardless of the future, what is certain is change. Independent of what changes occur, we must guarantee the right of free passage of U.S. and friendly flag carriers in and through space as well as deny that ability to space capabilities that threaten our national security interests in time of war. We must guarantee that free right of passage because, as we will see through the examination of the principles of war, space systems can make valuable contributions to our land, naval, air and space war-fighting forces, whether in day-to-day, peace time operations or as we employ whatever force is required to meet our national security objectives.

A Return to First Principles

For years the military has considered space in the context of mission areas (i.e., communications, navigation, etc.) or tasks (i.e., space control, force enhancement, etc.). Unfortunately, much of the way we currently view space systems is channeled by these convenient, but often over-simplified definitional areas to which the role of satellites has been assigned. Today's thinking overwhelmingly assigns satellites to a support role, assisting terrestrial warfighting. Modern day thought about satellites stands where our thinking about the airplane stood at the early stages of World War I - as scouts or messengers. Most contemporary thought about the contribution of space systems to the military has started from today's requirements, and most of it, while making valuable contributions to current thought, has concentrated only on pointing out current shortfalls and describing how to make only small incremental advances to today's state of the art. Those advances have been aimed at satisfying near-term requirements. None has gone back to "first principles", attempting to tie this new warfighting medium with its remarkably new, often counter-intuitive operating environment into a set of fundamental warfighting principles. This is the new ground that we shall break here.

We will set aside the conventional approach to gain new insight into future space systems by returning to the often-discussed Principles of War. We shall explore how space systems can contribute to the successful execution of future warfare using those time-tested warfare Principles as a starting point.

Principles of War - Definitions and Impact of Space Systems

We have considered three types of contributions that space systems can make to future warfare: (1) as support to all terrestrial warfighting, (2) as support to land, naval and air components, and (3) as a separate, unique warfighting arena. We list each Principle, define it, and then summarize our conclusions about the impact that space systems can have on future warfighting.

Objective - ***Direct every military operation toward a clearly defined, decisive, and attainable objective.***

Space provides the means for precise coordination of beyond-the-horizon land, sea, air and space operations, and will contribute to the outcome of conflicts either as weapons or as critical parts of the military decision cycle. They will assist in the direction of fire and the targeting of weapons, especially as space systems become critical parts of weapons loops. Increasingly, the objective of space control will be a prerequisite for effective land, sea and air control.

Defensive - ***Resist attack or aggression through appropriate operations, positions, or attitudes.***

Detection satellites will provide warning to terrestrial forces, giving the time needed to defend against attack and gain offensive initiatives. Against the proliferation of tactical ballistic missiles they will be critical in determining where an attack came from and how to respond. Information gathering provides indications of enemy actions and intentions, to optimize defensive positions. The proliferation and omnipresence of space assets will make defense of terrestrial assets much more difficult. Multiple space assets, cueing with terrestrial assets, will make defensive concealment more difficult. Satellites will assist in narrowing the number of defense corridors to be defended. Combinations of active and passive satellite defenses will enhance each other and will strengthen the defensive posture. While physical attacks from earth to space will be discouraged by the large amounts of energy and expense required, physical and other defensive anti-satellite measures such as directed energy weapons will still be required to gain space control and to degrade or deny enemy use of space. Physical attacks from earth can be discouraged by "keep-out" or self-defense zones, with the zones depending not only on distance from the defended satellite but also on time and energy considerations that are required to approach a defended satellite. The attack potential from space will stimulate the development of defensive weapons and countermeasures such as lasers, directed energy, and kinetic energy weapons. Defenses such as antijam, maneuver, and mobile TT&C, will be required for space system defense, and improved ground-based satellite position, identification and warning systems will be required to provide an adequate defense.

Offensive - ***Seize, retain, and exploit the initiative. Act rather than react.***

Proliferated satellites will provide timely information to globally dispersed users, assisting coordinated offensive operations among multiple forces. Communications satellites will provide military connectivity for coordinated operations; environmental satellites will optimize the efficient routing of forces; and navigation satellites will provide for positioning, timing and coordination of forces. For tactical operations, navigation satellites will provide the common

reference frame necessary to assure strike force connectivity. Long range terrestrial offensive weapons supported by space will increasingly threaten all fixed and moving targets. Offensive operations against satellites will first include physical attacks from the ground and inevitably later from space, directed energy attacks from the ground and space, and the use of jamming and other forms of electronic warfare. Farther in the future weapons in space are inevitable. The ability to strike targets directly from space will revolutionize warfare. Any nation that can target terrestrial forces with a space-based weapon can produce a substantial global threat. Such a capability will provide a strong incentive for the development of precisely targeted weapons from space to ground or space to space.

Security - ***Act to assure that the enemy will not acquire an unexpected advantage. Take continuous positive measures to prevent surprise and preserve freedom of action. Use both active and passive defense.***

Physical security of forces will be enhanced by satellite-derived knowledge of enemy space order of battle and knowledge of enemy concentrations. Satellite security will be enhanced by decoys, autonomy measures, shielding, hardening, maneuvering, proliferation, concealment, shoot-back, and other forms of physical defense. Space system security will be enhanced by redundancy and on-board data processing. Secure communications will be provided by encrypted communications, use of signal relays, spot beams, frequency hopping, and electronic counter countermeasures. Cross links will tend to eliminate the need for secure ground station relay points. Software security will assure successful operations under stress, and care and attention will be needed to avoid "Trojan horses", system take-over, and software sabotage.

Surprise - ***Strike the enemy at a time, place, and manner for which the enemy is neither prepared nor expecting an attack.***

The high dependency of the military on satellites will make space a good candidate for initiation of hostilities. Moreover, an attack on space assets is less likely to provoke escalation than a terrestrial attack. Surprise strikes will result from satellite collection, and synchronization of those strikes involving separate force components will be aided by satellites. Covert deployment of spacecraft capabilities, the activation of satellites assumed dead or dormant, and unconventional use of satellite capabilities will enhance surprise. Strikes conducted directly from space will give a new surprise dimension to warfare. Surprise concerning future enemy weapons capability can be minimized through the use of technical intelligence, aided by satellite collection. Satellites can also provide early warning of attack, acting as a "trip wire" to reduce surprise.

Mass and Concentration - ***Concentrate or focus combat power at the decisive point in space and time.***

Rapid deployment and dispersal of forces will be aided by satellites, both to support normal operations for forces on the attack and to avoid attack. Using space systems precision target interdiction effectiveness will be considerably improved. Navigation satellites will provide a uniform position and time grid permitting massing, rendezvousing and refueling, close-in surgical strikes, and concentration of forces to take place with increased precision. Moreover, navigation satellites will reduce the possibility of troops becoming lost or disoriented in battle. Forces will take advantage of satellites that are operated synchronously with each other,

performing such missions as focusing information collection, relay and point-to-point communications. Space manifestations of the principle of mass include satellite asset apportionment, concentration of satellite coverage capability, the concentration of energy to perform time-dependent missions, and the capability to surge. Mass concentration of satellites can be provided by more assets of the same kind on orbit, and the affinity of satellites to operate in key clustering locations (e.g., low earth orbit, geosynchronous and sun synchronous orbits, the Lagrangian points, etc.). Larger numbers of satellites in orbit will degrade more gracefully, provide better timeliness, provide more rapid collection, drive more rapid dissemination, provide better system endurability, complicate enemy targeting solutions, and complicate an enemy's ability to determine satellite system missions and functions.

Concealment and Deception - ***Hide forces from observation. Cover, mask and disguise them. Mislead, delude, beguile, and divert the enemy by all possible means.***

Space systems can be used to assist in the detection and identification of concealed forces. Locations of military forces can be denied to space systems only by effective deception. Because of the multiplicity of space systems, deception against detection must be effective against many systems, and the high probability against simultaneous deception will be a major driver of the need for antisatellite weapons. Collection and dissemination of false data by satellite will deceive an enemy, while properly executed satellite deceptions will draw an enemy to vulnerable locations. Space system mission areas can be concealed by design and other techniques because missions and functions of hostile satellites are difficult to assess. Effective use of these designs will contribute to surprise and survivability. Maneuvers can be employed deceptively. The natural cycle of "first conceal, then deceive, then engage" is applicable to space as well as to other forms of combat.

Economy of Force - ***Allocate minimum-essential combat power to secondary efforts. Execute attacks with appropriate mass at the critical time and place without wasting resources on secondary objectives.***

Space systems increase the effectiveness of terrestrial combat systems and proper use of those same ground-based systems will enhance the effectiveness of assets in space. Satellites will optimize target sets for strikes by a spectrum of weapons systems, and will reduce the need for organic assets. Space systems will allow a better determination of optimum attack/defense force ratios. In general, the transfer of good information between ground and space-based assets will optimize the use of all weapons systems, assuring economy of action.

Maneuver, Timing, Speed and Tempo - ***Place the enemy in a position of disadvantage through the flexible application of combat power. Maneuver your strength selectively against an enemy's weakness while avoiding engagements with forces of superior strength. Involves flexibility in thought, plans, and operations. Execute military operations at a point in time and at a rate which optimizes the use of friendly forces and which inhibits or denies the effectiveness of enemy forces. Dominate the action, remain unpredictable, and create uncertainty in the mind of the enemy.***

The keys to effective use of satellites in wartime are rapid tasking, timely data collection and fast delivery of targeting information to the shooter. Such a process will operate in an environment of near real-time, near-continuous coverage of force movements by space

systems. More accurate position determinations from satellites, combined with accurate timing of maneuvers, will lead to better coordination of strikes and maneuvers, tighter operational timing, higher speed maneuvers, and more effective use of smart munitions. Better satellite-derived positions will permit forces to fight battles at more advantageous times and places. Position-location will permit advance routes to be preprogrammed for low echelon use, increasing the effectiveness of vehicular and other platform maneuvers and force coordination.

Deployment - ***Rearrange forces for the attack or spread them out to minimize effects of enemy attack.***

Space systems will provide very precise timing and position information for force deployments and the optimum, timely execution of those deployments will be improved. Vectoring of forces onto strategic and tactical targets will be more effective through the use of precise navigation information. The global communications provided by satellites will optimize deployment of forces; space will continue to be a major player in strategic deployment. A rapid on-orbit replenishment, replacement, or deployment capability for satellites will be required under most wartime military scenarios. Satellite deployment will consist of launches on schedule, surge on demand, or the activation of satellites stored on orbit.

Simplicity - ***Prepare clear, uncomplicated plans and clear, concise orders to ensure thorough understanding. Give quick, clear, and concise guidance. Provide clear, simple, and unencumbered command structures, strategies, plans, tactics, and procedures to permit ease of execution.***

Communications are simplified through the simultaneous coordination of land, sea, air and space units. Common navigation techniques provides a common grid used by many different fighting platforms to simplify both offensive and defensive operations. In the smaller satellites of the future, standard satellite buses and standard launch vehicles will simplify operations. There will be a concerted effort for ground station controls not to require highly-skilled and trained personnel for routine activities. Space system design will be done with user-friendliness as a principle of paramount importance, from the design details to preparations for launch, to spacecraft TT&C, through spacecraft tasking, to the delivery of mission data to the overall systems operation.

Battlefield Friction, The Fog of War - ***Varying levels of confusion will exist during combat engagements which will confuse the m.***

Denial of information will tend to blind operating terrestrial forces, reducing their effectiveness and slowing them down, and the disruption of satellite communications will be a major contributor to battlefield confusion. Whether the source of failure of a satellite is a "soft" attack or a mechanical failure will be a primary source of confusion in future conflict. Disruption of relay satellites will be a force multiplier in the fog of war, for many links to decisionmakers will take place simultaneously for many operating satellites through relay satellites.

Doctrine and Training - ***Prepare, qualify, and educate personnel to fully understand their role in the conflict, the capabilities and limitations of all weapons systems that will aid or threaten them in battle, the methods of employment of those weapons, and their principles of operation.***

All terrestrial users of space system products must know their capabilities and limitations and this will require extensive training. Good training in space matters will be an important part of space doctrine. All forces will be taught how to avoid enemy space reconnaissance and all forces will be taught how to use friendly space assets to their advantage. Exercises, simulations, operations research, and war gaming are important components of doctrine and training. Because of the features of space that make it unusual and distinct from the features of terrestrial operations, space warfare will be different from terrestrial warfare. The operating environment of space is different than those in which other forces operate, necessitating a different approach to the military use of space. The potential for space assets to aid or hurt an airland operation must be taught. As the enemy begins to cue his space assets more effectively, the tactics of land, air and sea warfare will require change. Many of those changes can be identified through exercises, simulations, operations research and war gaming. In future major wars, space will no longer be a sanctuary; conduct of future operations there will be important to war's outcome. That importance must be taught, and good, supporting doctrine must be formulated and continually tested. War plans will include consideration of friendly and hostile space systems, and they will address the impact of space system degradation on terrestrial operations. Space doctrine, training and war plans will incorporate the use of commercial and foreign satellite systems in wartime, as appropriate. Exercises will continually probe the minimum required level of wartime communications.

These features of doctrine and training are necessary because the orbitology of the movements of space assets obey an altogether different set of principles than do those of more familiar terrestrial force platforms. Unmanned military assets operating in an often hostile, frictionless vacuum for months at a time requires non-traditional, often counter-intuitive approaches and thinking. Its effective use requires good training. Space is not merely an extension of air warfare; it is another warfighting medium. The effective use of space in warfare will require retraining, rethinking, and paying concerted attention to operations research, exercises, simulations and war gaming.

Summary

Time-tested Principles of War have given us new insights about the use of space systems in future warfare. These principles are still adequate to accommodate this new arena of warfighting. In fact, a review of the functional areas and the principles lead us to several key drivers that need to be stressed in any future space architecture. These drivers are (1) viable R&D programs for developing promising satellite concepts like we now have for developing new ships, tanks and aircraft; (2) centralized command and control, coordination of doctrine, training and operational concepts for the use of satellites; (3) decentralized mission execution (tasking and dissemination of information); (4) effective interoperability across functional areas; (5) ability to plan and coordinate employment of space systems with forces to be supported; (6) assured mission capability; (7) cohesiveness of space systems where each system complements the other; (8) timeliness of tasking, data collection and dissemination; (9) user-friendliness; and (10) simplicity of the data flow.

Possibilities for the Use of Current and Emerging Technologies to Enhance Future Warfighting Capabilities Using Space Systems

Robert Rosenberg

Joint Warfighting

Future warfighting will be joint. From the US perspective it will be high-tech, regardless of whether it will be directed against a high tech or a low tech enemy. The cutting edge we achieve in future conflict will depend on the types of capabilities in which we now invest. Against a high tech enemy, our advantage will depend on the extent to which our new capabilities exceed those of the enemy. Against a low tech enemy, who may use a myriad of novel, low tech, unconventional, guerrilla, terrorist, high tech/low cost, subversive, or fifth-column tactics against us, our advantage will depend on how efficiently our high tech arsenal can be used against those threats and how effectively we can address them.

The Requirements Process Favors "Stand-Alone" Systems

Partly because of the way the military uses the requirements process and partly because the acquisition process tends to encourage "stovepipe" weapons systems, we have become accustomed to designing systems that "stand alone," that serve a relatively small set of warfighters, or that lack what is being referred to as "horizontal integration." During times of budget plenty we could get by with this view of systems development, but in times of budgetary drought we must approach systems development differently.

Our current requirements process tends to develop an approach to systems by forcing any new system to satisfy a rather rigidly proscribed set of requirements. If a proposed system gives an 80 per cent capability at 40 per cent of the cost, it tends to be rejected because it does not meet enough of the requirement. The fact that it may be a relative bargain with a high "bang for the buck" ratio, that it may fit nicely into an vacant "niche" among our spectrum of weapons, or that it makes a significant contribution to a current capability shortfall goes unrecognized during a process in which we often find that the 100 per cent solution is unaffordable, especially for space-related activities.

Recognition of this situation is of vital importance because many aspects of our technology development process are tending to develop capabilities that best match small scale, low cost additions to what we are already doing or that take advantage of systems that are already in place or are being used for other purposes. We have tended to neglect add-on capabilities from space, low cost solutions that meet only a fraction of the requirements, or solutions that require both land and space nodes to be successful.

The Need for Synergy Between Space and Other Weapons Systems

Our military approach to space has tended to ignore much of the potential that space systems could afford to the warfighter, largely because they are expensive, stand alone "stovepipes." In the mid-1980s, Navy space advocates wanted to orbit a system known as NROSS (Navy Remote Ocean Sensor System). This proposed satellite had a number of sensors aboard that operated in concert to do remote sensing of ocean conditions from space. It had a stand-alone capability. No attention had been paid to collections that might have been routinely be

made by buoys at sea, collected by satellite and forwarded to some central manned collection point, although that possibility could have led to a much cheaper total collection system. This stand-alone approach to space must be abandoned, and with that abandonment must come the recognition that space systems should be designed into our collection systems of the future.

Sensor-to-Shooter Operations

We have experienced the remarkable contribution that GPS technologies have made to military operations in the Gulf War. Aside from contributing personnel, the only investment that the military had to make to achieve that extraordinary success was the purchase of small, inexpensive, hand-held GPS receivers. The rest of the satellite infrastructure was contributed by others.

Technical advances that have increased the sensitivity and sophistication and decreased the size, weight, and cost of some types of sensors have brought the evolution of these sensors to the point where military investment in their use could lead to the same marked advances to warfighting that we have experienced with our GPS receivers. We are at the point where we can tie sensors to fusion points or directly to shooters in real time and deliver weapons rapidly on target.

Generically, we can locate our sensors on aircraft, UAVS, or on the ground and provide them connectivity to the shooter through either space or airborne assets. Just as GPS receiver investments promise to change the way the military conducts its operations, investment in other types of sensors that can be placed on the battlefield by aircraft or special forces, could also revolutionize the way we operate. Our investment would not be in high-cost space assets, but rather in more affordable ground or air-based sensors that communicate information in real time to our shooters through a space or an airborne communications link, many of which already exist.

It is conceivable that strikes, triggered by these sensors, can be made within seconds of receipt of sensor information that can reveal where and what to shoot.

Candidates for sensors types and technology/system development include, but are not limited to, those appearing in Table F - 1.

Table F - 1. Sensor Type

Acoustic detectors with or without interferometry	Mass Transport Sensors (air mass, H_2O mass, flow indicators)
EM/ELINT collectors	Weather/Meteorological collectors
Optical/IR/UV/Thermal/Temperature detectors	Gravity measuring sensors
Multispectral/hyperspectral detectors	IR Tripwires
Particulate/Fog detectors	Radar Detectors
Pressure Sensors	Laser Detectors
Chemical/Molecular/Exhaust, etc. detectors	LADAR
Motion detectors	LIDAR measurers
Siesmic detectors	GPS Reciever components in other collectors
Interferometers of various types	Attitude Sensors-Pitch sensors
Wiretapper collectors	Status Sensors
Spoofers	Triangulation/Interactive arrays
Nuclear detectors	Using GPS techniques to track
Magnetic/Electro-detectors	Human/Spy reporting
Acceleometers	Imaging Radars
Ground Moisture Sensors	Railroad Track Counters
Cutouts and relay systems	

The lesson to be learned from our experience with GPS in the Gulf War is that we should be taking more advantage of ground-based service investments, which, when in place, have some type of link or connection to space or aircraft assets.

Small Satellites and Aircraft Collection

Since the inception of the ill-fated ARPA Lightsat program, a number of small military satellites to satisfy military collection requirements using platforms that were less costly, more plentiful (hence more timely), and less stringent in their collection requirements when such issues as resolution were considered. The ARPA MACSAT, a store-and-forward communications satellite, was effectively used by the Marine Corps in the Gulf War for logistics purposes. That satellite cost less than $10M and filled a “niche”. The Navy has flown special purpose satellites for ocean research.

InfoSoldier - An Example of Sensor-to-User Application

InfoSoldier originated in the Army but has a wide joint application to warfighting. At a projected cost of less than $65 million, InfoSoldier takes the name and the location of every company-level headquarters in theater, combines it with simple company unit status information, and sends it through space-oriented communications links to all headquarters levels in theater from battalion to the theater commander, keeping CONUS informed—all within 2 minutes of transmission. It promises to revolutionize situational awareness and reduce fratricide. InfoSoldier involves CECOM and the Battle Command Battle Lab, and uses an ASPO experiment, Grenadier BRAT, as a precursor to a full-up capability. The Navy has a similar concept, called SABER, that could be effectively merged with InfoSoldier. InfoSoldier has joint operational capability.

Broadening *InfoSoldier* to a Joint Forces Air Force Leadership Concept

As we move into the 21st century, the missions the military forces are being challenged with are changing. Important implications of these changes include better command and control of forces, increased situation awareness, and information dominance. General mission needs include requirements for timely battlefield intelligence to support targeting and battle assessment, implying integrated imagery and intelligence, better assured communications, and better and more current weather. Concomitant needs include capability to train as we fight, and to incorporate space into exercises, including use of simulated or virtual capability, as well as objective capability.

The following will address two of these specific requirements: 1) Capability to provide full knowledge of friendly forces status in the theater in a three-dimensional view, providing situation awareness to address integrated operations and that they can project a battle into, and 2) Ensuring availability of sufficient communications to support the ballooning information requirements, providing bandwidth on demand.

1.0 Two concepts are described in this paper which address the specific required capabilities. They are:

1) *Provide situation awareness to support integrated operations.* As concepts for digitization of the battlefield evolve, it will become more necessary to have a complete and continuous picture of the deployment and status of all friendly force units, and to minimize the amount of interceptable communications required to facilitate this big picture. The concept to address this need employs the capability to broadcast LPI signals which include GPS positions/velocity and other status about the transmitting forces, and relaying the information to ground for use in force planning and assessment. This use will include fusion with other data, providing local area scenes with current position of all friendly forces, as well as the situation of the forces, e.g., munitions remaining, mission status, etc. Primary system components include LPI transmitters, satellites with appropriate signal reception and data recovery capability, ground fusion and tactical comm.

2) *Better assured communications, providing bandwidth on demand.* To support theater operations in the 21st century, there will be a need to significantly increase area communications and communications capacity to CONUS. One general concept provides communications

as tactical augmentation, in highly elliptical orbits tailored to contingency areas, to augment "fixed" MILSATCOM and CRAF'd sources, affording secure "bandwidth on demand" to the theater with cross links to provide coverage to CONUS as well. Canisterized rounds would be ground maintained until needed, with capability to recover/refurbish the satellites for subsequent use. These satellites would be designed for relatively short life times, and the resulting radiation hardness levels would be reduced.

2.0 The following develops the concepts summarized above, providing operations concepts, sub-system concepts, and summary of enabling technologies and associated status.

2.1 LPI Force Reporting System Concept

As stated earlier, the purpose of this concept is to provide total battle space awareness via communications of theater wide status of forces. For this system, each theater force entity (e.g., maneuver squad, SOF group, aircraft or aircraft flight, etc.) would embody a transmitter which would aperiodically transmit a low power, spread spectrum pulse that would contain position and velocity information and status of mission and stores. Transmissions would be collected by satellites equipped to detect, acquire, and process the transmissions. Downlink data structures containing all such data will be created for broadcast into the theater. Ground reception and processing stations would be capable of recognizing and extracting those receptions in their sphere of influence, and of incorporating the resulting data into their situation assessment and associated force planning. In the event specific access to a force entity is required, the potential would exist to interrogate that entity using narrow bandwidth, low data rate communications (similar to pager operations) to request status.

- *Situation Assessment Concept* - This system augments other information by providing periodic updates on all friendly forces in the theater(s). As a GPS based information source, it will provide accurate positioning for battle arena entities that will reduce the possibility of fratricide. As a down-linked set of information, it is available to multiple planners simultaneously within the theater, and can be readily made available to pilots' heads-up displays to augment existing knowledge of friendly forces location and status.

2.1.1 Improvement to AF Capabilities/Operations.

This LPI Force Reporting System concept will provide theater command and control with full knowledge of the location, configuration and mission status of the friendly forces while minimizing the probability of enemy detection of the friendly forces, since their transmission will be LPI. This capability should enable better and more timely force engagement planning, better tracking of the covert forces, etc. This data transmission concept also provides a good vehicle for covert data transmissions, enabling more timely knowledge of mission status and location of the covert forces.

2.2 Tactical Deployment of HEO Communications

The burgeoning requirements for supporting all levels of deployment, in parallel, with more timely imagery, intelligence and video data to support the planning, execution and assessment of missions will create a tremendous demand for supporting communications bandwidth.

This concept addresses providing the world-wide availability of sufficient bandwidth to support joint force operations.

2.2.1 Description of System Elements

This set of satellites would be stored at ground locations, prepared (canisterized) for launch on as-needed basis, maintained in orbit for a period of time required to support contingent operations, then de-orbited and recovered, refurbished and readied for next use. An initial concept for the satellites would be combined UHF and EHF, providing signal communications compatible with other communication systems in use, including commercial satellites. However, to provide relatively high bandwidth capability, use of alternative communications structures, e.g., direct broadcast satellites with multiple T1 channels, should be considered. Orbits would be HEO, tailored to provide high-throughput theater-level communications. Satellites would be provided with cross-links to facilitate around the world communications. Satellite design would accommodate requirements for thermal and shock conditions at re-entry and to achieve a soft-landing.

- *Launch Concept* - The launch vehicles would be designed for minimum maintenance and handling. Processing would be highly automated, requiring a very minimum launch support personnel contingent. Launch time and orbit requirements would be determined to specifically support the contingency conditions, and launch parameters automatically entered into the launch vehicle flight computer and verified.
- *Ground Equipment Concept* - There is little change in existing and planned ground equipment for the operations within the theater. If the resulting concept is DBS based, small DBS antennas would be placed at theater command and control nodes to enable the receipt and filtering of the broadcast data to minimize the impact on the deployed operations. Secondary broadcast of the appropriate data to requesting units would be done from the theater C2 nodes. The ground equipment associated with minimum hands-on management and launch of canisterized launch vehicles at Western range will require significant planning and development. However, the Russians have been conducting launch operations in this fashion for years, so the technology is available, and not driving.

2.2.3 Improvement to AF Capabilities/Operations.

This concept for tactically deployable communications provides for rapid augmentation of communications to accommodate rapid growth in communications requirements to manage increasing growth in multi-spectral imagery and situation assessment information. In addition, the concept provides for rapid reconstitution of C2 capability in case of loss of communications.

ACCU-Strike Weapons Use of Differential GPS for a Pin-Point Strike Weapon

These concepts will allow our military to deliver high explosives onto preplanned, stationary targets with accuracies of some tens of inches. Differential GPS is the key to the concept since GPS alone offers accuracies of only 20 meters (60 feet) or worse. GPS accuracy, while

quite good, is usually larger than the radius of the target, so even higher accuracies are desirable differential. GPS offers accuracies of inches, so that weapons can potentially be delivered within inches of the center of even a small target. This means that it is possible with this delivery concept to use only one sensor system from shooter to target and thus avoid the additional expense of two or more sensor pass-offs that are often characteristic of other weapons systems. It also means that more accurate targeting can be done at lower cost.

In the concepts described above, the target is stationary and the accuracy of weapons delivery onto the target is of the same order as our ability to measure the position of the target in the first place. The differential GPS technique is so accurate that the uncertainties in the position of the target will probably dominate the targeting solution.

This class of weapons would have a high element of surprise. These weapons concepts would be relatively inexpensive and relatively hard to counter.

Satellite Station-Keeping and Offensive Operations at the Geostationary Orbit Using Very Long Baseline Interferometry (VLBI) Techniques

Satellite Station Keeping: Sets of three, 1-5 foot diameter antennas located about 1 km apart at any latitude between the equator and about 45 degrees latitude and linked with a fiber optic line to a central computer could be used to provide station keeping for satellites located along the geostationary arc. Normal emissions from the satellites or friendly beacon frequencies located on the satellites would be simultaneously observed by the three antennas and fed into a central processor which would then use Very Long Baseline Interferometry (VLBI) techniques to determine their relative positions along the geostationary arc.

VLBI techniques have been used by radio astronomers since the mid 1960s. With those techniques, they can determine the positions of antennas located at intercontinental distances to a precision of less than 10 centimeters. This technique can be used to monitor satellite positions with a precision that is of the order of less than a spacecraft diameter. Current orbit keeping is restrained to keep-off distances of the order of 1 km or more. The ability to "pack" the geostationary orbit in this way will enable thousands more geostationary satellites to operate simultaneously along the arc. While this will place stringent conditions on the use of radio frequencies since the satellites would operate quite near each other, the ability to accurately station keep will be worth many millions or even billions of dollars as the geostationary arc becomes more and more crowded and the ability to accurately station keep to this precision allows more satellites to operate very close to one another.

Offensive Operations at the Geostationary Orbit: When a friendly satellite is nearing the end of its useful life in geostationary orbit, it is moved outward into an orbit that goes around the earth a few times per year. If the near-dead satellite were to have a beacon aboard that could be turned on and off over very short intervals of time, the position of the near-dead satellite could be determined to an accuracy within its own diameter using VLBI techniques. In the above paragraph we saw that it was possible to determine a target satellite's position using its own emissions by tuning a ground based receiver to the frequency of the emitting satellite. Thus, if we can determine both the target and the near-dead satellite positions to high precision,

and if there is still a small amount of station keeping ability left in the near-dead satellite, it should be possible to slowly steer the near-dead satellite into the active target satellite, hitting it and putting it out of commission. When this activity is applied to several pairs of satellites at once, there is the possibility of putting several target satellites out of commission within a relatively short interval of time. If done surreptitiously, the enemy would not know what was happening. Targeting solutions could be run at frequent intervals, with the best combinations quickly chosen when needed.

Use of Direct Broadcast Satellites for Warfighting Support

The commercial market is planning to use direct broadcast satellites (DBS). They will have worldwide coverage. While the use of these commercial satellites by the military often presents problems, they can be used for selected purposes in defensive postures. We should include the use of these satellites use as part of our satellite support structure. Routine use of DBS satellites would be preferable because it would continue to add to our experience base. Barring that, arrangements can be made to use bandwidth in certain situations, similar to the arrangements made for the use of commercial aircraft.

There are many uses to which DBS availability could be put. They include the real-time transfer of information of all kinds in theater, the contents of which are needed by many echelons of command simultaneously. DBS satellites can do tailored multicasting in theater. Point-to-point transfer of information at high data rates could take place worldwide. Processed information, including unit ID, location and unit status of forces in the vicinity, derived from initiatives like InfoSoldier, could be automatically tailored and transferred to many units on the battlefield, including the lowest ones, at low data rates.

Use of Beepers for Warfighting Support

Military planners would revise many of their warfighting procedures if there were the capability to do simple paging on the battlefield. At the moment, such paging is available commercially within CONUS, but it will rapidly become available worldwide. At present, the least sophisticated paging capacities consist only of simple information transfer such as an alert signal. More sophisticated devices contain a string of alphanumeric information as well, permitting the transfer of more information, perhaps in coded form.

The ability to page on the battlefield has many potential uses, among which are:

- Transmitting an alert to perform a particular action (e.g., attack, perform a function, achieve simultaneity, look at an information update, etc.)
- Transmitting a short message to confirm an action
- Other types of short messaging

A two-way beeper system, with an uplink as well as a downlink, would offer a very powerful combination of capability on the battlefield, because its line of sight access would permit simple connectivity to all units in theater. The improvement in the timelines of situational awareness of battle units would be remarkable if the system were properly planned

A Library Database in Orbit

While the use of direct broadcast satellites and battlefield beepers would aid military operations, the presence of an instantly accessible database of information would be useful to a commander. The database could consist of: (1) long-term information which might be changed infrequently by means of command updates from the ground, and (2) short-term information which might be changed on time scales of less than a day. The information content in those databases might include the following types of information:

Long term information

Weapons system information - friendly and enemy

Platform information, including capabilities

Procedural instructions

Short term information

Order of battle and status of units

Satellite ephemerides

Enemy battle frequency and signals information

Hidden messaging

Use of Bi-Static Radar Space Illuminators

Orbiting satellites emit radiation that falls on wide areas of the earth's surface at a variety of frequencies. These emissions vary in intensity, but they might be used to provide a bi-static radar capability in conjunction with aircraft collectors operating near the ground to catch the reflections and make use of them.

Emissions from transmitters, if strong enough, can be used by collectors, if large enough, that are strategically placed in order to provide a trigger for detecting and tracking objects such as aircraft or incoming missiles that pass through and disturb the field produced by the radar. Scanning algorithms can be developed to search in space and time and to increase the effective integration time, hence provide a good signal-to-noise ratio, to detect and track the threat as it passes through the radiation field. Candidate satellites range from commercial communication satellites, TV DBS satellites, down to the constellation of GPS satellites.

Emerging Technologies that are Ripe for Exploitation

Examples of key technologies in the recent past are: the global positioning system which has permitted our military to perform coordinated maneuvers as never before; lasers which can designate targets so that munitions can strike with high precision; radars which can detect and track moving targets; and night vision devices that give our troops a decided competitive edge in night warfare.

While our future vision is not 20/20, we can venture an intelligent guess at some key enabling technologies of the future, including:

- Fiber optics and laser communications that permit information databases to become rapidly synchronized around the world through ground and space communications, respectively
- Aided target recognition techniques that take the output of aircraft and space sensors and analyze them to recognize the presence of targets more quickly
- The incorporation of differential global positioning techniques to permit targeting to fractions of a meter
- The use of hyperspectral collection techniques from the air to spot enemy threatening targets and from space, combining spectral and subpixel recognition techniques
- Bi-static radar techniques that use emissions emanating from spacecraft to assist in target detection on and nearer the ground, and
- The emergence of new methods to store energy so that our spacecraft and our warfighters can operate more independently for longer periods of time, assisted by long-lived, battery-powered, high-tech equipment

This list only scratches the surface of what may lie in store for us.

If we now focus on additional critical technologies that are space-related, we can derive the following list of enabling technologies that deserve attention:

- A*dvanced materials*

Advanced alloys, ceramics, composites, and polymers

- Directed energy

Directed energy systems that include lasers and radio-frequency devices. Breakthroughs in optics, improved device efficiency or propagation through the atmosphere could lead to a revolutionary space-related weapon.

- Guidance and navigation

These technologies are needed for better precision guided munitions that can be coupled closely to space systems

- *Information management technology*

Advances in information systems and sensors generate large volumes of data which must be efficiently managed and exploited for military operations. Relevant technologies support the management of exceptionally large databases and the products of real-time, large-scale information retrieval systems. These databases are often physically distributed among many sites separated by great distances, like the Internet. Battlefield surveillance data must be fused from multiple sources in near real-time, requiring high data rates.

- *Information warfare*

Uses high-power microwave, electromagnetic pulse, and radio frequency technologies that are capable of jamming, upsetting, or damaging spacecraft electronics from the ground.

- *Microelectronics*

Further emphasis is needed to gain increases in performance in higher temperature semiconductors and opto-electronics, to enhance on-board processing systems, and to improve both guidance and control, and command, control, and communications abilities.

- Power storage and conversion

High energy density and low mass power supplies, pulse power supplies, and high power solid state switches support the development of more effective weapons-delivery and reconnaissance vehicles, and of radars, jammers, other electronic warfare systems, and directed energy weapons.

- *Propulsion*

Propulsion technologies, such as advanced rocket propellants and exotic fuels, support the development of better aerospace platforms and permit heavier payloads.

- *Sensors*

Advanced sensors support intelligence collection, strategic warning, treaty monitoring, and weapons targeting. Advances in sensor technology enable increased performance in all-weather detection, identification, and military targeting. Sensor needs include better space-based radars, wider field optics, and more efficient infrared detectors. Fusion of all types of data collection and the integration of processing and communications capabilities need attention and improvement.

- *Signal processing*

Signal processing technologies support more efficient extraction of information derived from signals received from sensors. As signal processing technologies advance, more decision-making processes can be automated (see *User-friendly system development*, below). Signal processing technologies include software correlation techniques, neural networks, algorithm development, and artificial intelligence.

- *Software engineering*

Software engineering includes software development and maintenance technologies as well as signal processing software. Applications include the control of large digital switches for telecommunications, battlefield surveillance systems, air defense systems, and ballistic missile defense.

- *Space warfare modeling and simulation*

There is a need for a well-equipped joint space warfare center, not related to missile defense issues (which would tend to divert attention away from critical space issues). In that center, space-related studies and analyses should be undertaken by operators and doctrine developers working together, to understand and use more effectively

the space systems that are available, including national space systems and the interface between space and aircraft collection. The center should be oriented toward the development of concepts of operation and modes of employment of all types of existing and proposed space systems, the refinement of requirements, and the submission of substantive input to the design of future military and intelligence spacecraft of all kinds. It should test the efficacy of using commercially available space launch and space collection capabilities and the worth of their products. No single service or organization should do this alone. Human decisionmaking should not—and cannot—be modeled, but the human use of spacecraft products can.

- *Survivability*

Survivability technologies involve those materials and techniques designed to enable a space system to operate in a hostile environment that requires hardening against natural radiation, man made jamming and all types of systems upset.

- *User-friendly system development*

As automatic systems and massive information flows become more prevalent, the human in the loop will increasingly become a bottleneck to the speedy execution of tasks. There is a need to help human intervention and human decisionmaking in the form of filtering, information control, and data digestion to improve all aspects of the machine-human interface.